A REVIEW OF THE JUSTIFICATION PROCESS FOR THE NAVSUP OPERATIONS AND MAINTENANCE BUDGET

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THESIS

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FOR THE NAVSUP
OPERATIONS AND MAINTENANCE BUDGET

by

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for the NAVSUP
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by

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I. INTRODUCTION

The purpose of this paper is to review the recent evolution of the NAVSUP (Naval Supply Systems Command) budget justification process. The principal area of interest will be the NAVSUP OMN (Operations and Maintenance, Navy) budget. The budget process of every federal agency has been forced to undergo extensive change since the introduction of the planning, programming, and budgeting system (PPBS) during the early 1960's. PPBS has broadened the application of statistical, mathematical, and economic techniques in the budgeting area. As a result, budget justification based on intuition alone unaided by objective, quantitative analysis has been unacceptable to Department of Defense (DOD), Congress, and the President for some time. Indeed, as the pressures to cut budgets increase, even better justification is needed.

Several of the goals of PPBS seem to be stimulating recent NAVSUP efforts. One goal of PPBS is to measure the output of a given program in terms of its objectives. For example, the effectiveness of various stock points can only be determined in relation to a particular set of objectives. Concentrating stock dollars on high demand items may prove highly effective when measured by net availability, the percentage of demand requests for standard stock items normally stocked at an activity receiving the request.

But if the objective is to serve the customer,a comparison of stock points on the basis of such a measure of effectiveness would be inappropriate and misleading. In this regard we can contrast net availability with point of entry (POE) availability (the percentage of initial entry demand requests issued by the activity receiving the request). Looking at the average FY 1973 1N cog availabilities, net availability was 82%. Simultaneously, the POE availability for the same group of items was 50%. The stock control officer at a stock point might be happy with satisfying 8 out of 10 demands for stocks that should have been in the bins; however, to a repair officer, the same 8 issues out of a requirement for 16 line items (a 50% POE availability) would probably be unacceptable. Similarly, in evaluating the entire supply corps effort at budget time, it is not sufficient to speak of availabilities, but what the effort produces in terms of increased fleet operating hours – how many hours of equipment downtime awaiting parts are eliminated.

The objective of the Naval Material Command (NAVMAT) is to maintain a particular equipment in operating condition for a specified fraction of time [1]. This fraction of time is defined as operational availability (Ao) and is equal to the ratio of "up" time to total time.

Symbolically,

$$Ao = \frac{MTBF}{MTBF + MSRT} \quad *$$

where

MTBF = Mean Time Between Failures

MSRT = Mean Supply Response Time.

Operational Availability can be increased by increasing MTBF or by decreasing MSRT. MTBF is affected by the design and characteristics of an equipment's components and is the responsibility of the hardware systems commands. On the other hand, MSRT is affected by the availability of spare parts and the performance of the distribution system. These are, to a great extent, the direct responsibility of the Navy Supply System. Accordingly, one objective of NAVSUP is to achieve lower levels of supply response times (MSRT) for failed equipments and weapon systems while expending as little as possible for procuring and distributing spare parts.

Another crucial aim of the PPBS concept is the analysis of alternatives to find the means of reaching basic program objectives for the least cost. The goal is to force federal departments to consider particular programs not as ends in

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*See Chapter IV for a more exact discussion of Ao.

themselves — to be perpetuated without challenge or question — but as means to objectives, subject to the competition of alternative and perhaps more effective or efficient programs. PPBS seeks to suppress the practice of incremental budgeting where the allocation process consists primarily of increasing or decreasing existing programs without evaluating the program's comparative contribution to the attainment of some specified objective.

This aspect of PPBS has caused NAVMAT to look at NAVSUP and NAVSEA for example not as two organizations to be perpetuated just because they now exist, but instead, to consider them as alternate competing programs whose outputs affect the fleet's operational availability.

In response to this aspect of PPBS, an analytical economic model is needed which will enable NAVSUP to successfully justify its requests for investment and expense budgets. This model must, in quantitative terms, enable NAVSUP to convince Navy, DOD, and Congressional budgeteers that proposed expenditures offer the least-cost way of providing various levels of benefits to the operating elements of the Navy. The formulation of such a model must consider the Supply System's interaction with maintenance by determining the effect on operational availability of expenditures for the Supply System to reduce MSRT versus equivalent expenditures for the hardware commands to increase MTBF or purchase more end items. One approach might be to calculate the increase in MTBF needed to achieve the same effect on Ao as

a proposed decrease in MSRT. The discussion of such a trade-off can only be useful in justifying budget requests if costs can be associated with proposed changes in MTBF or MSRT. The costing methodology must be kept simple and utilize currently available data.

The final goal of PPBS considered here is to establish these analytic procedures as a systematic part of budget review. PPBS seeks to subject policies and programs to analysis and to integrate the decisions into the budgetary process. This integration is encouraged by the fact that the allocation of limited budgetary resources among competing claims can best be made if fuller information and analysis of program objectives, effectiveness, and costs are available. When relatively narrow choices are involved – such as the allocation of operating dollars among various stock points – analysis can contribute greatly to program decisions. But even when broader questions are being considered – such as allocation between maintenance and supply – analyses that present the payoffs or consequences of each program can assist the decision maker in weighing the alternatives.

These then are the aims of PPBS that seem to be stimulating recent NAVSUP efforts: the evaluation of program output as it relates to specified objectives, the analysis of competing alternative programs, and the integration of policy and program decisions with the budgetary process. The current NAVSUP budget backup procedure was developed in the early

1960's because of the inadequacy of the method then in practice. That method used as the only workload indicator the number of line items issued. Projections were made by adjusting this indicator by the planned percentage change in Navy force levels. The current approach is a statistical procedure which uses a broader base to relate more directly NAVSUP's efforts to changes in force levels. It uses historical data relating to several workload indicators — not just the number of line items issued — and uses three selected force level indicators corresponding to ships, aircraft, and personnel. Correlation analysis (see Appendix A) is used to quantitatively describe the degree of relationship between the force levels and NAVSUP workload.

Although the above procedure does apply some statistical analysis in the projection of budgetary requirements, it does not relate the output of NAVSUP activities to increased fleet operational availability, nor does it analyze the tradeoffs between maintenance and supply. In 1971 the Chief of Naval Operations (CNO) directed that the Ships Supply Support Study (S^4) [19] be undertaken by NAVSUP to develop a set of procedures that could be used annually by the Navy as part of PPBS to justify and allocate budget dollars to supply support. The study directive noted that there did not then exist any way of describing the relationship between the budget dollars allocated to supply support and supply support effectiveness that is indicative of the readiness of fleet

units. The directive further noted that although several "supply effectiveness" procedures intended to measure specific aspects of internal supply system efficiency had been developed, e.g., net and POE availabilities, measures of that sort do not provide CNO with the criteria required for the efficient allocation of budget dollars to supply support.

The S^4 study was completed in June 1973 and demonstrated that many supply questions can be addressed in terms of the effect on requisition response time and on resulting equipment availability. One major criticism of the study was that it never associated costs with perturbation of availability or throughput time. The study attracted great interest in reducing MSRT; within a month of the final S^4 report, NAVSUP directed the Fleet Material Support Office (FMSO) to establish a separate department (the Supply System Performance Evaluation Department — SSPED) to collect and monitor response-time performance information and to devise and propose methods for reducing response time. In addition, billets for Operations Analysis officers were established at all ICPs and four supply centers. The Commander of NAVSUP, Rear Admiral Wallace R. Dowd Jr., began a series of articles in the December 1973 Supply Corps Newsletter encouraging readers to be aware of fast response time as NAVSUP's number one goal and to contribute ideas on improving response time.

Still, a methodology was needed by NAVSUP to justify its resources when competing at the budget table with alternate

programs such as maintenance. In February of 1974, NAVSUP requested FMSO to develop a model of the supply system that takes into account the interaction of supply, maintenance, design and end-item production in sufficient breadth and detail to permit statements of benefits and trade-off possibilities. More specifically, FMSO was requested to develop a model to assist in the justification of the NAVSUP OMN budget. A model was proposed by FMSO during May of 1974 and it is currently in the validation stage. A discussion of that model is found in Chapter V.

II. THE NAVY SUPPLY SYSTEM

The Navy Supply System is administered by the Naval Supply Systems Command (NAVSUP), which is one of five Systems Commands subordinate to the Naval Material Command (NAVMAT). NAVSUP is directly responsible to the Chief of Naval Operations (CNO) for providing the material support to the operating forces of the Navy. Figure 1 shows the NAVMAT organization.

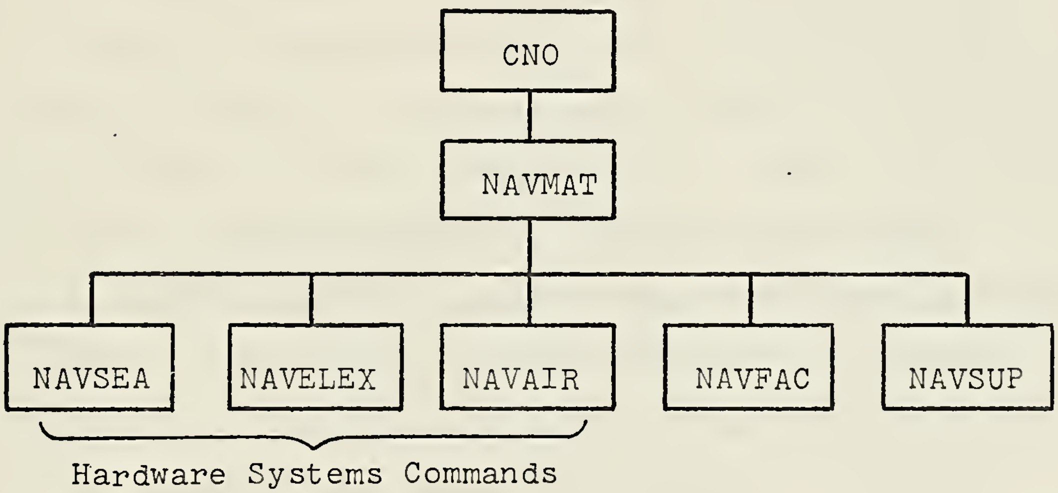

FIGURE 1. NAVMAT Organization

NAVSUP is responsible for supply management policies and methods; administration of the Navy Supply System, publications and printing; the exchange and commissary program, the Navy Stock Fund, the field procurement system, transportation of Navy property, and material functions related to materials handling equipment food service, and special clothing. Of the four million items in the DOD Supply

System about 1.7 million are Navy-interest items. Almost half of the Navy-interest items are managed and controlled by NAVSUP through its two directly-managed Inventory Control Points (ICPs), the Aviation Supply Office and the Ships Parts Control Center. The hardware system commands exercise inventory management over some 27,000 major items of material such as missiles, aircraft engines, ordnance, shipboard machinery, and electronics equipment. The remaining Navy-interest items are managed by DSA or GSA but are controlled for the Navy through the Fleet Material Support Office.

The prime characteristics of the operating forces: their readiness, mobility, and endurance prescribe the form of support which the Navy Supply System renders. The fleet is virtually always mobilized — only the tempo varies. Conceptually, Navy fleet supply support is based upon an organic level of supply and two echelons of resupply. The organic level provides the material specified in the Coordinated Shipboard Allowance List (COSAL) or Aviation Consolidated Allowance List (AVCAL). The range and depth of material on the allowance list is tailored to each specific ship and is computed to provide balanced support for an average endurance period of 2 1/2 months. The first echelon of combat resupply consists of the ships of the Mobile Logistic Support Forces (MLSF) which include tenders, repair ships, and replenishment ships. This force is augmented by a very few overseas depots. This echelon of fleet support

backs up the allowance list material carried in the combatant ships. The second level of resupply provides the materials located predominantly at the tidewater supply centers in the United States. These supply activities serve as the material reservoir and act as pipelines between industry and DSA/GSA supply systems and the fleet. Supply Centers issue Navy-, DSA-, and GSA-managed material both to the MLSF ships and directly to the operating fleets.

In addition to fleet support the supply centers provide support to the activities of the Shore Establishment: the air stations, ordnance stations, shipyards, training stations, and small shore activities. The Inventory Control Points determine the range and depth of items to be carried at specific locations; position these inventories at the supply centers; and determine, in collaboration with the hardware systems commands and the customers served, the individual support missions that the supply centers will carry out.

A. THE FORCES SUPPORTED BY NAVSUP

All funds required to operate the active forces of the Navy, except military personnel costs, and the costs of related support activities are appropriated by Congress under the title of Operation and Maintenance, Navy (OMN). These funds include amounts for pay of civilians, contract services for maintenance of equipment and facilities, fuel, supplies, and repair parts for weapons and equipment. Financial requirements for these funds are influenced by a variety of

factors. The principal factors are force levels such as the number of aircraft squadrons, military strength and deployment, rates of operational activity, number of installations, and quantity and complexity of major equipment (aircraft, ships, missiles, etc.) in operation.

The programs covered under OMN appropriations which relate to the active forces of the Navy are described below.

(1) Strategic forces. — The submarine missile fleet consists of 41 boats which deploy 656 Polaris and Poseidon missiles. Estimates for 1975 reflect conversion of additional submarines from Polaris to the more advanced Poseidon ballistic missile.

(2) General purpose forces. — These forces consist of the Navy's tactical air forces comprised of land, and carrier-based antisubmarine and attack air wings and Navy combatant and support ships. During 1975 the Navy will operate over 5400 aircraft including over 1300 fighter and attack planes. Naval forces include 15 aircraft carriers, 118 submarines, 65 amphibious ships, antisubmarine forces, antiair forces, and auxilliaries totalling 508 active fleet ships. These operating forces are supported by 172 major Navy shore activities including 15 naval stations and 34 naval air stations. Five nuclear submarines and one nuclear powered guided missile frigate will be introduced into the fleet in 1975, bringing to one-third the proportion of warships that are nuclear propelled. Seven other new ships will become operational including the first three of the 963 class

destroyer, a new type of amphibious assault ship (LHA), and two of a new class of patrol hydrofoils (PHM). The addition of these modern vessels will permit further inactivation of overage and obsolete vessels.

(3) Central supply and maintenance. — This program includes funds for specialized supply and maintenance activities. It provides resources for the determination of inventory levels, procurement (excluding acquisition costs), storage, distribution, depot-level maintenance and transportation of Navy materiel. These functions are Navy managed and conducted at various locations worldwide at six supply centers, two inventory control points, and 22 industrial support facilities including shipyards and repair facilities.

(4) Other programs are training and medical, administration, intelligence and communications, and support of other nations.

B. THE OMN BUDGET

Table I on the following page shows the Navy's recent OMN budget as approved by the President for FY 1975. Table II shows further detail for NAVSUP's portion of that budget.

These OMN appropriations as budgeted to Central Supply and Maintenance have many possible allocations among the Systems Commands. For any component of the Navy there exist major logistical alternatives as to the use of these appropriated funds. For illustrative purposes, these tradeoffs are discussed for carrier-based aircraft.

TABLE I

Operation and Maintenance, Navy Budget (millions)

	FY 73 (actual)	FY 74 (est.)	FY 75 Navy Submit	FY 75 OSD Adj	FY 75 Pres. Budget
TOTAL	5410.2	6635.6	7527.1	-236.1	7291.0
1. Strategic Forces	317.9	348.5	465.8	+3.6	469.4
FBM systems	278.3	302.9	414.4	-5.8	408.6
Support Ships	25.0	29.1	33.8	+8.4	42.2
Other	14.6	16.5	17.6	+1.0	18.6
2. General Purpose Forces	1808.5	2635.0	3091.4	-30.0	3061.4
Aircraft forces	239.7	274.0	279.3	+70.4	349.7
Ship forces	974.7	1619.6	1968.5	-168.0	1800.5
Base operations	420.3	484.4	605.4	-5.6	599.8
Training	53.1	70.3	72.6	+19.7	92.3
Other	120.7	186.7	165.6	+53.5	219.1
3. Central Supply & Maint.	2051.3	2203.7	2383.5	-137.1	2246.4
NAVAIR	781.5	906.5	1000.0	-140.3	859.7
NAVORD } NAVSEA(1JUL74)	281.0	269.9	315.1	-22.1	293.0
NAVSHIPS } NAVSEA(1JUL74)	330.3	360.0	354.6	-9.5	345.1
NAVELEX	72.4	70.9	79.8	-7.1	72.7
NAVFAC	119.1	120.0	155.1	-13.3	141.8
NAVSUP	423.1	*422.1	423.7	+55.5	*479.2
NAVMAT Command	43.9	54.2	55.0	- .1	54.9
4. Other Programs	1232.5	1448.3	1586.4	-72.4	1514.0
Training & Medical	722.7	833.0	969.5	-50.8	918.7
Administration	178.2	278.1	249.7	-21.2	228.5
Intelligence & Comm.	288.1	315.2	342.7	+3.4	346.1
Support of other Nations	43.5	22.0	24.5	-3.8	20.7

*The FY 1974 total as of June 1974 was estimated at 414.4. The FY 1975 NAVSUP total in the Congressional apportionment request submitted in June 1974 was 525.9.

Some totals do not agree due to rounding.

Source: FY 1975 Presidential budget Submission of Feb. 1974, DOD Extract [20].

TABLE II

Summary of NAVSUP OMN Budget (thousands)

	FY 73 (actual)	FY 74 (estimate)	FY 75 (estimate)
By Element of Expense:			
Civilian Wages	220,336	230,388	241,095
Transportation of things	140,543	129,502	216,605
Utilities and rents	12,600	13,763	15,831
6 other categories	49,671	40,717	52,330
TOTAL	$423,150	$414,370	$525,861
By Functional Category:			
Mission operations	140,441	135,354	148,031
Personnel support	31,132	37,084	42,257
Base services	14,419	14,757	15,617
Administration	58,816	62,445	63,355
Supply operations	157,824	144,238	229,942
6 other categories	20,518	20,492	26,659
TOTAL	$423,150	$414,370	$525,861
By Program Element:			
Supply Depots/operations	120,763	117,753	126,879
Inventory Control points	94,454	95,634	107,058
Procurement operations	24,844	23,615	22,656
Base communications	4,652	4,408	4,482
Commissary stores	30,908	36,688	41,854
Command	6,986	6,770	6,327
Second Destination Trans.	140,543	129,502	216,605
TOTAL	$423,150	$414,370	$525,861

Source: FY 1975 Apportionment Request of June 1974 [4].

C. MAJOR LOGISTICAL ALTERNATIVES

The general nature of the major logistical alternatives – that is, economic tradeoffs – is shown for support of carrier-based aircraft in Figure 2:

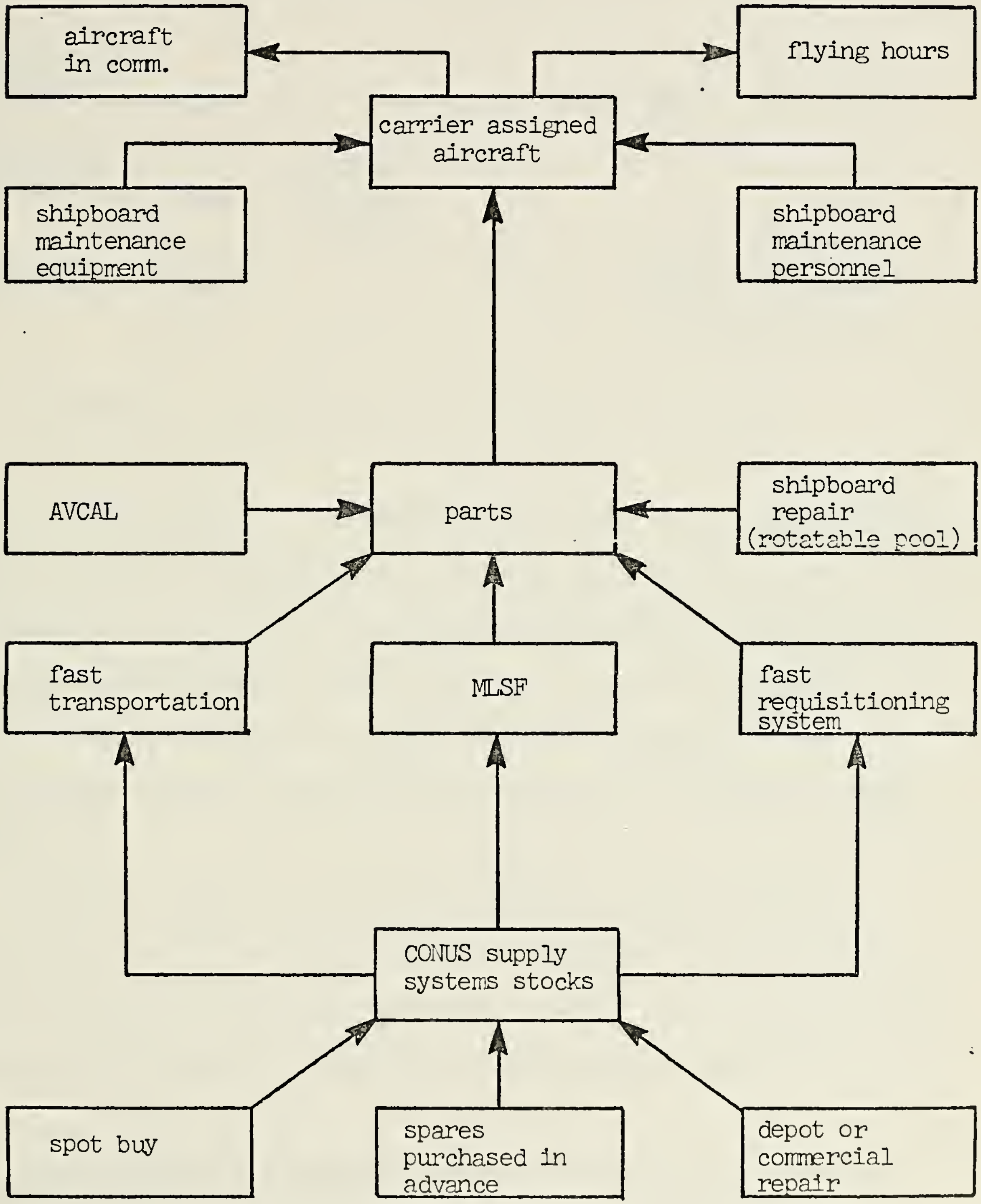

FIGURE 2. Major Logistical Alternatives for Support of Carrier-Based Aircraft

First, there is a carrier production function* [12] analogous to others encountered by economists in industry. As seen from the diagram below, the two primary outputs in this case are aircraft-in-commission (AIC) and flying hours.

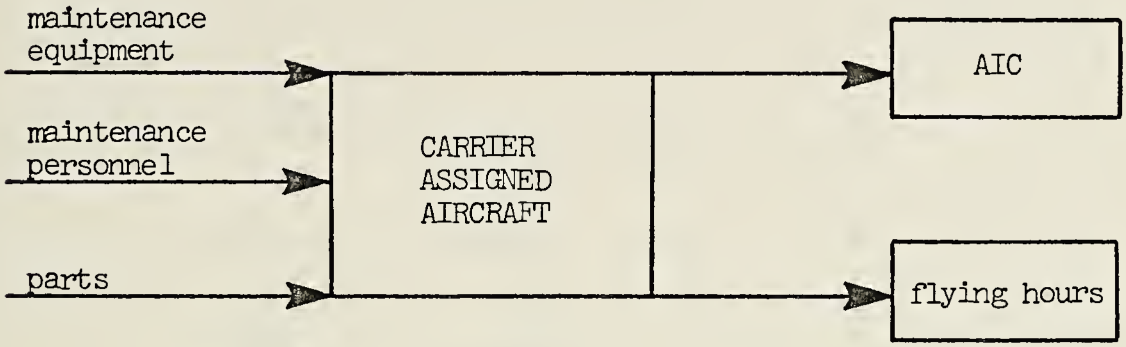

FIGURE 3. Carrier Aircraft Production Function

For a fixed number of assigned combat aircraft, the production of AIC or flying hours is determined by the mix of subsidiary inputs of (1) shipboard maintenance equipment – including workspace, test equipment, etc; (2) shipboard maintenance personnel – radar, engine airframe mechanics including contract civilians, etc; and (3) shipboard spare parts.

Second, there is an entire shipboard parts supply function. An F4 series fighter may include some 128,000 listed parts (excluding the engine parts), but the shipboard demand for most of these will be low or non-existent.

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*This chapter neglects non-logistical inputs such as flight crews.

Consequently, the broad alternative sources of parts supply on a carrier are (1) stock carried on board in the Aviation Consolidated Allowance List (AVCAL), (2) repairs on board in the Aircraft Intermediate Maintenance Department (AIMD), or (3) requisitions from a resupply source (MLSF ship or CONUS stock point).*

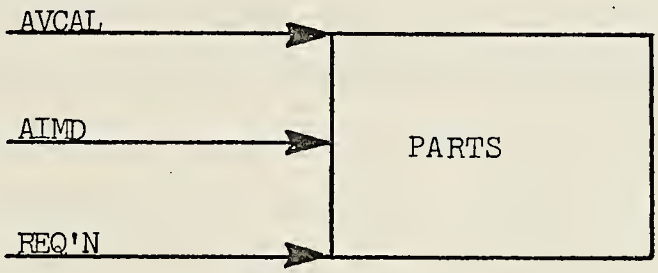

FIGURE 4. Inputs to Parts Production

Third, the requisitioning cycle of the carrier to a MLSF ship or a CONUS stock point and back to carrier may be shortened in various ways. The requisition can be passed by some means of electric communication (naval message or even AUTODIN**), rather than in some paper form (e.g., mail) that is physically transported from the carrier to the resupply activity. Requisitions can be processed more expeditiously, perhaps through the use of new electronic data-processing equipment. For example, requisitions presently being referred

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*Actions such as on board fabrication of the part or cannibalization are considered to be included in these three sources.

**AUTODIN (Automated Digital Information Network) provides high speed data transmission and switching capabilities linking all major supply data processing installations.

from a stock point to an ICP are sent via the AUTODIN network, but the two computers are not directly linked. Cards must be punched out by the stock point computer and manually input to AUTODIN. At the ICP AUTODIN terminal, cards are punched out and wait for up to an hour to be manually input to the ICP computer. The delays for manual processing are cumulative and could be eliminated entirely by better, albeit more expensive, equipment. The location of items at the warehouses and stock picking and packing can be further automated to obtain quicker service, but at higher cost. Transportation of the part to the carrier from the shipping activity can be by such varied means as railroad freight, air parcel post, railway express, truck, QUICKTRANS*, or more rapidly, by direct airlift. The above are means of reducing requisition response time. What is the economic worth of a faster requisitioning cycle? What is the most economical combination of communication, processing, and transportation that yields any given requisition response time? These are two worthwhile questions in themselves.

Lastly, for this analysis, there are procurement alternatives for the supply managers at the ICP. They can buy spare parts from the manufacturers and position them on the MLSF ships or at a stock point. A small but costly fraction of these parts are assemblies that can be economically repaired,

*QUICKTRANS is the Navy's nationwide civilian-contract air transport system administered by NAVSUP to provide rapid movement of high priority material.

either at an aviation repair facility or by private contractors. Or, if a part that has not been procured in advance is needed, it can be "spot-procured" for the individual requisition direct from the manufacturer who might have it available in stock or might have to produce it. The advantage of this latter procedure is that a final provisioning buy of spares can be deferred until more is known about actual demand usage and early design modifications have occurred.

The interactions within the Navy Supply System are so numerous and complex that it is difficult to view its effectiveness objectively. Zealous managers sometimes increase the efficiency of their own operation in ways that may lessen the overall performance of the logistics system. For example, transportation officers, who have some discretion in selecting the mode of shipment of a part, may give too much consideration to minimizing transportation costs and too little to the impact on NORS* or on requisition response time.

This chapter has described the responsibilities of the Navy Supply System as it pertains to the support of the operating fleets and discussed some of the problems of choice pertaining to Navy logistics. To help predict the consequences of alternative policies and practices, we may use models on paper, models in our heads, or models in the form

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*NORS — (Not Operationally Ready Supply). This refers to the operational status of an aircraft.

of computer simulations. In any event, the alternatives should be considered in terms of economic criterion. We should look at these choices as problems of getting the greatest capability from our limited resources.

III. JUSTIFICATION OF FY75 NAVSUP OMN BUDGET

A. BACKGROUND

The NAVSUP budget submission and justification process begins over a year before the start of the fiscal year under consideration. For instance, the FY 1975 submission to the Navy Comptroller (NAVCOMPT) was dated 25 July 1973. This basic budget request is prepared by adjusting the POM - 75 basic budget for wage board increases, price escalation costs, functional transfers, and all other known changes. After a review of this budget submission by NAVCOMPT, a revised budget is submitted to the Office of the Secretary of Defense/Office of Manpower and Budget (OSD/OMD) in late September or October. (The FY1975 OSD/OMB submission for the NAVSUP OMN budget was dated 1 October 1973.) In January preceding the beginning of the fiscal year, the Congressional submission is prepared. This document helps form the basis of the submission of The Budget of the United States Government which is submitted to the Congress by the President. (The budget message of the President for FY1975 was presented to the Congress on 4 February 1974.) Soon after, the Congressional committees begin budget hearings, and NAVSUP, like all other government agencies, is called upon to justify its requests for funds. By June preceding the fiscal year the modified budget is delivered to the Congress in the apportionment submission. (The FY1975 apportionment submission was dated 1 June 1974.) The

objective of the entire budget review process is to develop defensible, solid budget estimates for submission to OSD and Congress.

B. NAVSUP OMN BUDGET PROGRAM ELEMENTS

Throughout the budget-reviewing process, NAVSUP partitions its requests for OMN funds into the seven program elements: Supply Depots/Operations, Inventory Control Points, Procurement Operations, Base Communications, Commissary Stores, Command, and Second Destination Transportation. Funds for each program element are justified by relating requirements to a forecast obtained by using some budget projection technique. The procedure currently used by NAVSUP for each program element is discussed below.

1. Supply Depots/Operations

Funds requested under this program element are for the operation of supply centers and depots located in the United States under the responsibility of NAVSUP. These supply outlets are engaged in the receipt, storage, and distribution of military supply items. They form the core of the Navy resupply network required to sustain the operating forces and the supporting shore establishment. Workload at stockpoints is forecast on the basis of a significant correlation* which exists between selected supply workload

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*See Appendix A for a discussion of how the existence of this correlation was demonstrated.

at supply outlets and the force levels of the operating fleets (Ships, Aircraft, and Military Personnel).

Three measures corresponding to the forces NAVSUP supports are developed from force level data. The number of COSAL items is used to measure the force level of ships in the active fleet; the number of aircraft support items is used to measure the force level of the number of programmed operating aircraft in the fleet; and the number of active Navy military personnel is used as a direct measure. NAVSUP has found that using the number of support items for ships and aircraft is more representative of the forces supported than the use of the total number of ships and aircraft in the fleet. The total number of ships could remain the same from one fiscal year to the next; however, due to a change in the types of ships, the total number of ships' support items (our force level indicator) could vary. For instance, from one fiscal year to the next the Navy might retire two minesweepers (4000 support items each) and two diesel-powered submarines (8000); at the same time, three nuclear frigates (30,000) and one nuclear ballistic submarine (40,000) might be commissioned. Although the number of active ships remains constant, the number of support items (and hence NAVSUP's workload) increases by 106,000 items. As more complex and newer ships or aircraft, which require more support, enter the fleet to replace current forces, NAVSUP workload is projected using support items as

a representative measure of force level. In the case of the personnel force level, equal weights are assigned since support per person is considered comparable on the average.

In order to obtain an indication of the change in the forces which NAVSUP supports from one fiscal year to the next, an index for each force level indicator is calculated by dividing the force level indicator of the outyear by the one for the base year. Table III shows the indices for FY 1975 as 0.955 for ships, 0.990 for aircraft, and 0.978 for military personnel as the percentage changes from the base year of FY 1974.

Three measures selected to reflect NAVSUP's supply operations workload are (1) line items received and issued; (2) measurement tons received and issued; and (3) measurement tons in store. Estimates of the first two are projected using the force level indices discussed above. The third, being relatively insensitive to changes in force levels, is adjusted for planned changes only. Weighting factors are developed to connect base year workload totals to proportional splits between ships, aircraft, and personnel. This is done by using NAVSUP 1144 data* (or NAVSUP PUB 295) and assigning each material cognizance code and its attendant issues and receipts to either ships, aircraft, or personnel or a

*NAVSUP Form 1144, Supply Distribution and Inventory Control Operations Report, is submitted monthly by major supply distribution points (Centers, Depots, Shipyards, and Air Stations).

TABLE III

Summary of Force Level Indices Utilized in Computing FY 1975 Apportionment Request Workload Requirements

	FY 1974 (base year)	FY 1975 (estimate)
SHIPS		
Average Active fleet ships	548	510
Total ships COSAL items (000)	6,914	6,600
Index	1.0	0.955
AIRCRAFT		
Average Operating Aircraft	5,692	5,682
Total Aircraft Support Items (000)	447,860	443,310
Index	1.0	0.990
MILITARY PERSONNEL		
Average Active Military Personnel	558,000	546,000
Index	1.0	0.978

percentage split between any/all of these categories. Table IV shows the weighting factors for Line Items In and Out as 52% for ships, 19% for aircraft, and 29% for personnel. These weights are then applied to the total workload of 13,138,000 issues and receipts to obtain 6,832/2,496/3810 as the proportional splits (in thousands). The respective force level indices of 0.955/0.990/0.978 are then applied to obtain the projected proportional splits for ship/aircraft/personnel workloads of 6525/2471/3726. These are then added to obtain the projected number of Line Items In and Out for FY 1975 of 12,722,000. Similarly, the projected number of measurement Tons In and Out was calculated to be 6,751,000. Measurement Tons in Store is projected to remain constant at 1,898,000. Table V shows the actual force level indicators and the corresponding workloads for the last four fiscal years.

To obtain projected budgetary requirements, the relative changes in workload from base year totals are first converted to percentage variations. The percentage workload change between the current year and succeeding year is then applied to the current level of funding to determine budgetary requirements for each applicable area. These estimates are then increased for pay raises, increased health benefits, price escalation, known projects, or other special management programs and decreased for reduced funding of supply workload, functional transfers, or other reasons such as savings from base closures, etc. The fixed

TABLE IV

Derivation of FY 1975 Supply Operations
Workload Requirements (in thousands)

			FY 1974	Force Level Indices		FY 1975
Line Items In and Out (000)			13,138			
Ships	52%	=	6,832	x 0.955	=	6,525
Aircraft	19%	=	2,496	x 0.990	=	2,471
Military Personnel	29%	=	3,810	x 0.978	=	+ 3,726
			Projected workload:			12,722
M/Tons In and Out (000)			7,010			
Ships	69%	=	4,838	x 0.955	=	4,619
Aircraft	9%	=	630	x 0.990	=	624
Military Personnel	22%	=	1,542	x 0.978	=	+ 1,508
			Projected Workload:			6,751
M/Tons in Store (000)			1,898			1,898

TABLE V

Force Level Indicators vs. Ships Workload
(figures in thousands)

	FY 1971	FY 1972	FY 1973	FY 1974
SHIPS				
FL	9,891	7,923	7,263	6,914
LI	8,710	8,343	7,750	6,832
M/T	5,259	5,017	4,729	4,838
AIRCRAFT				
FL	461,800	455,503	444,835	447,860
LI	2,995	3,049	2,831	2,496
M/T	617	654	617	630
MILITARY PERSONNEL				
FL	658	613	576	558
LI	4,992	4,653	4,322	3,810
M/T	1,508	1,599	1,508	1,542

FL = force level
LI = line items in and out
M/T = measurement tons in and out (1 M/T = 40 cubic feet)

Source: yearly apportionment submission documents.

cost of facilities management is then added to obtain a final estimate for the Supply Depots/Operations program element. Table VI shows the figures for FY 1975.

2. Inventory Control Points

Funds requested under this program element are for the operation of ICPs under the responsibility of NAVSUP. The following are major considerations determining workload and funding requirements at the ICPs.

(a) The change in the annual rate of supply support items related to new ships and aircraft initially introduced into the fleet. Workload under this category consists of such efforts as provisioning, identification, and procurement of initial spares. The predominant workload factor and costs in this operation involve effort related to provisioning actions.

(b) The total ships and aircraft supply items required for continuing support to Navy force levels of ships and aircraft in the operating fleet. Workload under this category consists of such non-automated functions as reviewing stock actions, repositioning of material within the system, procurement of parts for immediate fleet use or system stock replenishment. The predominant workload factor and costs in this operation concern effort related to stock actions.

(c) Costs of program support for weapon systems and other logistic programs to maintain fleet readiness and to affect improvements in the supply management area.

TABLE VI

Supply Depots/Operations FY 1975 Budget

FUNDED WORKLOAD: Stock point workload that can be accomplished within funding availability approved as of June 1974 (in thousands)

	FY 1974		FY 1975	
	Workload	FUNDS($)	Workload	FUNDS($)
Line Items In and Out	13,015	43,032	12,631	43,494
M/Tons In and Out	6,810	47,783	6,650	51,513
M/Tons In Store	1,898	8,356	1,898	9,010
SUBTOTAL:		99,171		104,017
Facilities Management		18,582		22,862
STOCKPOINT TOTAL:		117,753		126,879

UNFUNDED WORKLOAD:

Line Items In and Out	123	285	91	230
M/Tons In and Out	200	1,094	101	539
TOTAL:		1,379		769

Two measures selected to reflect NAVSUP's ICP workload are (1) stock actions and (2) provisioning items reviewed. The count of stock actions by ICP is reported monthly and is already broken out by ships (SPCC*) and aircraft (ASO*). The base year count of provisioning items reviewed is calculated from the number of items actually selected to be introduced as spares during that year. A historical percentage (one for each ICP) is obtained from an annually-updated five-year average of items reviewed to items selected. This percentage is then applied to the report of the number of items selected to obtain an estimate of provisioning items which were reviewed during the base year.

The same force level indicators (less the count of active military personnel) as used to reflect the forces supported by NAVSUP stock points are used to reflect the forces supported by NAVSUP ICPs when forecasting the number of continuing support actions; however, new indices are prepared when forecasting the number of provisioning actions. This is because such workload is not due to the current number of ships and aircraft support items, but is due to the construction/conversion of new ships and the purchase of new aircraft. For example, when forecasting the number of stock actions the two indices as shown in Table III of 0.955 for

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*SPCC stands for Ships Parts Control Center. ASO stands for Aviation Supply Office. SPCC and ASO are the two NAVSUP ICPs.

ships and 0.990 for aircraft are used to show the percentage relationship of FY 1975 to base year 1974. The index for personnel is not utilized since this program element principally funds SPCC and ASO which support ships and aircraft, respectively, but are involved in little,if any, support of personnel. An index of 1.0 is used to relate both ship and aircraft provisioning workload since there was little change between FY 1974 and FY 1975 in the number of new aircraft support items and new ship construction/ conversion support items. Table VII shows the derivation of FY 1975 ICP workload requirements. For illustration of the provisioning support force level indices, Table VIII shows actual data from the FY 1973 OSD/OMB budget submission. Table IX shows the FY 1975 budget figures obtained by comparing workload and funds for the base year to projected workload to obtain a budgetary requirement. Adjustments are made to this figure to account for known factors like pay raises. To this figure are added projected totals for other Navy Management Activities, Logistic Support Programs, and funds for Facilities Management.

3. <u>Procurement Operations</u>

Funds requested under this program element are for supporting services/activities and for NAVSUP's share of Naval shipyard supply department costs. Funds requested provide for supporting services such as publication and printing costs, contract stevedoring, leased tankage, etc.

TABLE VII

Derivation of FY 1975 ICP Workload Requirements
(figures in thousands)

	FY 1974		Force Level Index		FY 1975 (estimate)
Continuing Support (Stock actions)	3,566				
SHIPS	1,760	x	0.955	=	1,681
AIRCRAFT	1,806	x	0.990	=	+ 1,788
	Projected Workload:				3,469
Provisioning Items	790				
SHIPS	625	x	1.0	=	625
AIRCRAFT	165	x	1.0	=	+ 165
	Projected Workload:				790

TABLE VIII

Illustration of FY 1973 OSD/OMB - Submission ICP Provisioning Workload Force Level Indices

	FY 1971 (base year)	FY 1972 (estimate)	FY 1973 (estimate)
New Aircraft	828	525	506
Total New Aircraft Support items (000)	74,733	65,989	63,000
INDEX	1.0	0.883	0.843
New Ship Construction/Conversion	38	17	15
Total New Ship Construction/ Conversion Support items (000)	525	517	484
INDEX	1.0	0.985	0.921

TABLE IX

Inventory Control Points FY 1975 Budget

FUNDED WORKLOAD: ICP Workload that can be accomplished within funding availability approved as of June 1974 (in thousands):

	FY 1974 Workload (000)	FY 1974 Funds ($000)	FY 1975 Workload (000)	FY 1975 Funds ($000)
1. Navy Item Management Activities				
a. Continuing Support-stock actions	3,533	28,799	3,339	28,503
b. Initial Support-provisioning actions	790	17,020	790	17,136
		45,819		45,639
2. Other Navy Management Activities		1,172		1,238
3. Logistic Support Programs		41,698		50,714
4. Facilities Management		6,945		9,467
TOTAL - ICPs		95,634		107,058

UNFUNDED WORKLOAD:

Continuing Support-stock actions	33	179	130	770

They also provide for costs of supporting activities such as the Navy Procurement Offices and the Navy Material Transportation Office. In addition, this program element includes funds to support Non-Navy Industrial Fund effort at Naval shipyards. Funds requested are calculated on the basis of staffing needs and other cost considerations incident to performing work in each specific area.

4. <u>Base Communications</u>

Funds requested under this program element are for leased communications costs at field activities/headquarters of NAVSUP. Requirements are determined on the basis of continuing reviews of workload demands for communications facilities and estimated utilization.

5. <u>Base Operations (Commissaries)</u>.

Funds requested under this program element are for civilian staffing at Navy commissary stores and for support received from the Navy Resale System Office (NRSO), Brooklyn, New York, for Navy exchanges and ships' stores. Requirements under this program are determined on the basis of projected sales volumes at existing commissary stores and the need to establish new stores where there are sufficient authorized patrons but no commissary facilities available. The funds requested are calculated on the basis of the civilian staffing needed to handle projected sales workload and costs associated with support received by the commissary store program from NRSO.

6. Command

The funds requested under this program element are to cover staffing requirements and related support costs at NAVSUP headquarters. Requirements are related to the minimum staffing necessary to provide central control and direction and other support to field activities. Funding requirements are based on the headquarter's staffing level and associated support costs.

7. Second Destination Transportation

The funds requested under this program element are for second destination transportation costs and terminal operations. These funds provide for the movement of supplies, material, and overseas military mail in support of the operating forces. Requirements are determined on the basis of the force levels to be supported, giving consideration to tonnage/dollar expenditure trends being experienced as adjusted for known change factors that would affect transportation/terminal workload and costs.

IV. RESPONSE TIME AS A MEASURE OF OUTPUT

As discussed in the introduction, NAVSUP is responding to the goal of PPBS that requires the analysis of the output of the Supply System in terms of its objectives. The number one objective of the Navy Supply System is stated below [21]

General Objective #1

> NAVSUP will provide optimum support in appropriate categories of supplies and services, responsive to the requirements of the Navy including project managers, other supported services and agencies, and allied nations under the International Logistics Programs. For general material, optimum support is that which maximizes requisitions satisfied within the time frame required by the requisitioner. For technical material, optimum support is that which minimizes downtime of weapons systems due to lack of repair parts and components.

This chapter is concerned with the development of an appropriate measure of Supply System output in terms of this objective as applied to technical material (repair parts or components of a weapon system). Notice that the above General Objective, in its last sentence, suggests a criterion for measuring technical material support effectiveness. This definition of "optimum support" can be interpreted as that which maximizes operational availability (the fraction of time a given equipment or weapons system is operational) by minimizing supply response time (the time required to requisition and assemble all the parts required to complete a corrective maintenance action). Consequently, a discussion

of the manner and magnitude of the relationship between supply response time and operational availability form the bulk of this chapter.

From an engineering viewpoint, availability historically has been thought of as mean time between failures (MTBF) divided by the mean time between failures (MTBF) plus the mean time to repair (MTTR), or

$$A_i = \frac{MTBF}{MTBF + MTTR} \equiv \text{Inherent Availability}$$

This is an idealistic view of the world assuming that all needed repair parts are available when needed. In the real world, delays are almost always incurred due to nonavailability of needed parts. To obtain operational availability from this equation, one must add mean logistic delay time (MLDT) to the denominator:

$$A_o = \frac{MTBF}{MTBF + MTTR + MLDT} \equiv \text{Operational Availability}$$

where MLDT can be thought of as the sum of mean administrative delay time (MADT) and mean supply response time (MSRT). Operational availability now becomes:

$$A_o = \frac{MTBF}{MTBF + MTTR + MADT + MSRT}$$

Investigations of actual data indicate that MSRT appears to average 30 to 40 times MADT and MTTR combined [1], and that MSRT is, in the eyes of NAVSUP, the driving factor in the equation for operational availability. In addition, the time to actually repair the equipment (MTTR – typically a few hours) is insignificant when compared with the time to assemble the parts (MSRT – typically greater than 100 hours). Consequently, for computational purposes, operational availability is usually viewed as

$$A_o = \frac{R}{R + S} \quad , \quad \text{where} \quad \begin{aligned} R &= \text{MTBF (Reliability)} \\ S &= \text{MTTR} + \text{MADT} + \text{MSRT} \\ &\cong \text{MSRT (Supportability)} \end{aligned}$$

To illustrate the importance of considering MSRT when discussing availability of an equipment, we can contrast A_i with A_o in an actual case where MTBF = 400 hours; MTTR + MADT = 6 hours; and MSRT = 240 hours.

$$\text{Inherent Availability (Ai)} = \frac{400}{400 + 6} = 0.985$$

$$\text{Operational Availability (Ao)} = \frac{400}{400 + 240} = 0.625$$

As these data point out, supply response time is a major factor in the availability equation.

The use of 240 hours (10 days) as an example of MSRT is not without justification. Remember, MSRT is the time to acquire all parts needed for a maintenance action; that is, MSRT = $\underset{i}{\text{maximum}}$ {MRRT* of i^{th} part} . Also, this 10 days average delay may be experienced even with 90 percent of the maintenance actions requiring parts being satisfied with onboard COSAL parts. For illustrating the computations involved, assume a maintenance action requiring only one part so that MSRT equals the MRRT of that item. Let the COSAL effectiveness for that item be 90 percent and the time required to resupply the part be 100 days. The calculation of MSRT would then be

$$\text{MSRT} = \text{MRRT} = 0.90 \times 0 \text{ days} + 0.10 \times 100 \text{ days} = 10 \text{ days } (240 \text{ hours}) .$$

In the above example, resupply is assumed to take an average of 100 days; in the case of extreme situations such as a ship's casualty, the supply system delay time may be only 15-20 days on the average. Assuming a COSAL effectiveness of 90% and a resupply time of 20 days, MSRT in these mission-critical situations would be more on the order of 2 days:

$$\text{MSRT} = 0.90 \times 0 \text{ days} + 0.10 \times 20 \text{ days} = 2 \text{ days}$$

---

*MRRT (Mean Requisition Response Time) is the average length of time to satisfy a given requisition.

Note that if COSAL effectiveness drops from 90 to 80%, MSRT doubles to 4 days!

$$\text{MSRT} = 0.80 \times 0 \text{ days} + 0.20 \times 20 \text{ days} = 4 \text{ days}$$

To get an insight into the relationship between Ao, MTBF, and MSRT we can use our simplified relationship $Ao = \frac{R}{R+S}$ to examine the marginal benefits (in terms of increased Ao) of improved reliability (R) or improved support (S). The partial derivative of Ao for small <u>decrease</u> in S is

$$-\frac{\Delta Ao}{\Delta S} = \frac{R}{(R+S)^2}$$

and Figure 5 shows the results for fixed values of R = 50,200, and 400 hours. These results tell us that, at least in terms of current performance, we will produce more operational availability (Ao) if we spend our resources reducing MSRT on equipments with relatively high reliability values rather than if we spend those same resources on equipments with low reliability. (If MSRT is already low, the opposite is true).

We now compute and plot "production functions"* with inputs R and S for various fixed operational availability

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*A production function is a technical relationship telling the amount of output capable of being produced by each set of specified inputs.

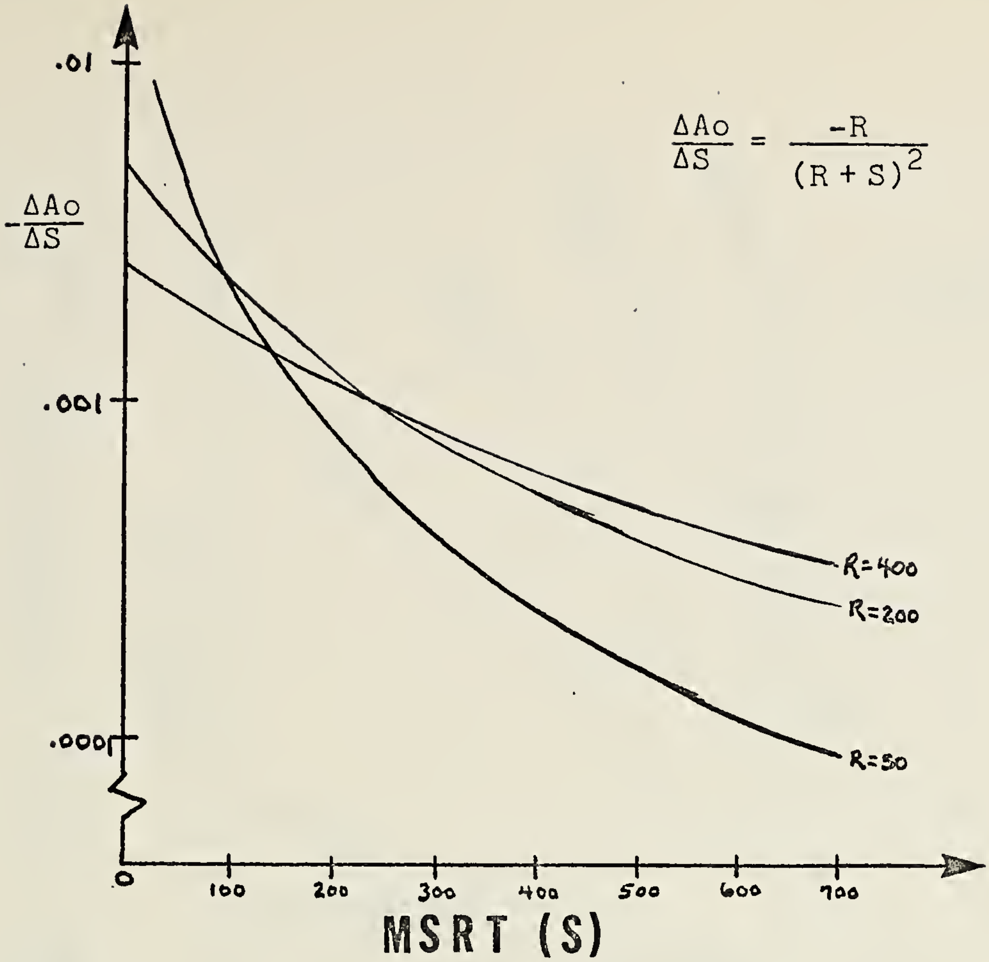

FIGURE 5. Marginal Changes in Ao as a Function of MSRT

values. Figure 6 presents the results. Notice the relative "payoff" per increment of increase in R as compared to an incremental decrease in S. The dotted lines indicate increases in Ao of 20% from 0.20 to 0.24, 0.50 to 0.60, and 0.70 to 0.84. Examine the ratio of ΔR to ΔS for these 20% increases in Ao. At Ao = 0.70 this requires 32 units of R to produce what alternatively can be produced using only 6 units decrease in S.

There is a different story for Ao = 0.20 (MSRT four times larger than MTBF, say R = 50 and S = 200 . . . see Figure 5). As Figure 6 shows, to improve Ao from 0.20 to 0.24

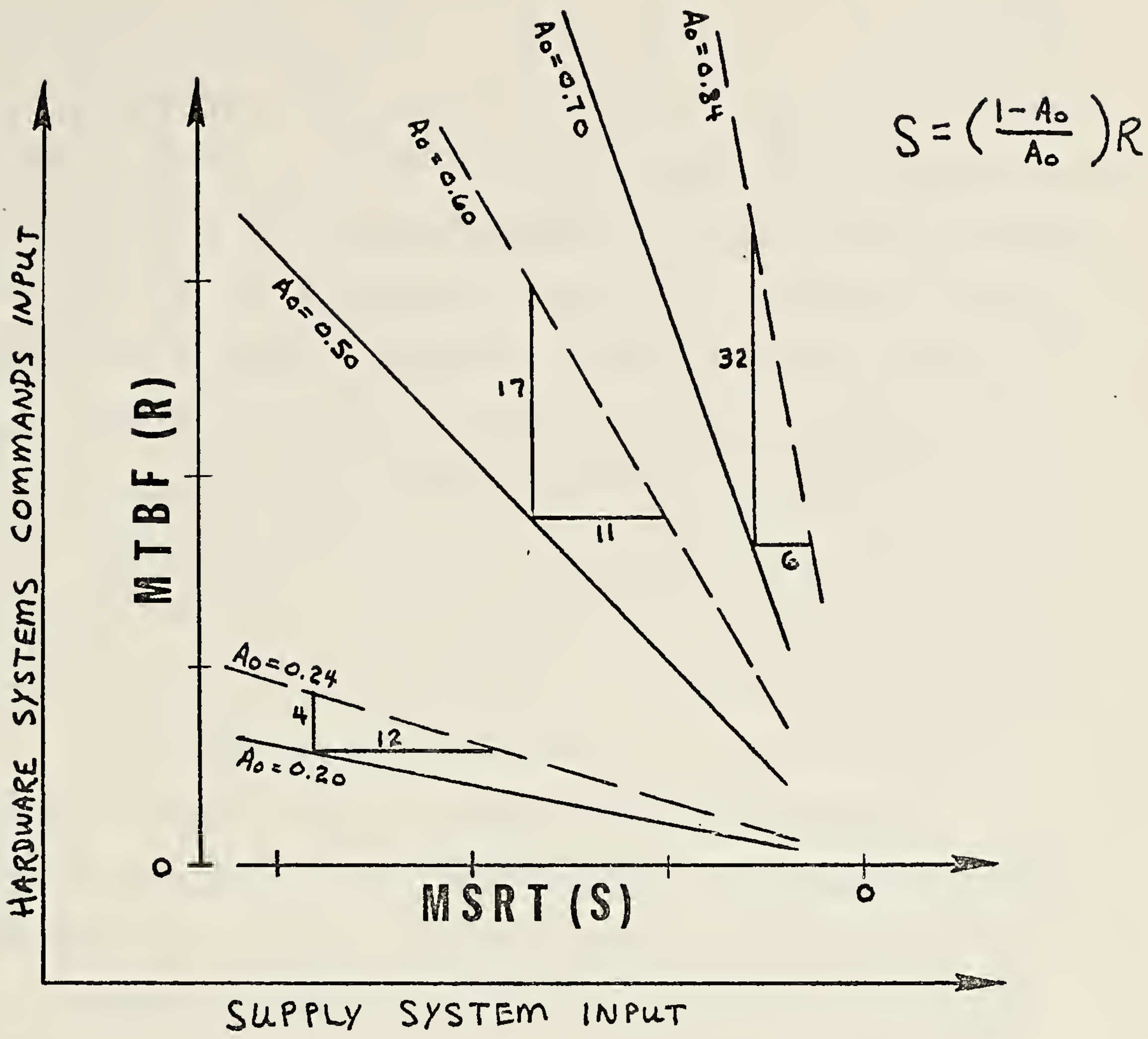

FIGURE 6. Contours of Operational Availability (Ao)

The contour lines of Ao do not extend to the origin because reduction of MSRT to values close to zero hours is not a realistic alternative to increasing MTBF.

it takes only 4 units increase in R as compared to 12 units decrease in S. When R and S are equal (Ao = 0.50), we again have to decrease S less than the increase in R for the same 20% increment in Ao. With the development of cost information such as the cost of higher reliability or the cost of faster requisitioning, this approach could help us improve upon our decisions as to the allocation of scarce resources during design, development, and provisioning of weapons systems. These tradeoffs between MTBF and MSRT are important considerations when you have options with respect to investment in reliability or supportability; however, for most operating equipment there are severe limits on our ability to improve MTBF. It therefore, becomes important to know how and to what extent improvements in MSRT can be accomplished.

The Ships Supply Support Study (S^4) investigated various equipments empirically to provide some insights into the effect of MTBF and MSRT on Ao. To illustrate the current lack of appropriate information, out of the original 275 equipments chosen for investigation, only 38 had the necessary data in the 3-M data files to facilitate the parametric analysis. Among the data required were equipment identification codes (EIC) from which MTBF and MTTR are obtained and the EIC code cross reference to ship so that ship steaming hours can be determined.

A graph of Ao versus MSRT is useful for pointing out the impact on availability of reductions in MSRT. Such a graph can identify an equipment whose reliability is either so good

or so bad as to rule out improvement of MSRT as a means to improve Ao significantly. There might be two reasons for the inability of MSRT to significantly improve Ao: (1) the equipment hardly ever fails (as reflected by a very large MTBF) or (2) it hardly ever works (as reflected by a very low MTBF). In either case a significant improvement in Ao by improving supply alone is hopeless – in the first case (high MTBF), happily unnecessary, and in the second case (low MTBF), unhappily true. For this reason, equipments can be segregated into three groups with respect to MSRT: (1) those equipments for which Ao can be significantly improved by effecting lower MSRT (typified by Figure 7); (2) those equipments whose reliability is so high as to insure very high Ao regardless of MSRT (see Figure 8); and (3) those equipments with such a low MTBF (high frequency of failure) that even substantial reduction in supply response times have little effect on Ao (illustrated by the equipment in Figure 9). Of the 38 equipments analyzed by S^4, the distribution over the three groups was about equal.

MSRT is the only factor of Ao that NAVSUP can influence to any extent, since MTBF and MTTR are directly influenced by the Hardware Systems Commands and the fleet commanders. Consequently, NAVSUP considers MSRT as its most important output where less is better than more. MSRT is itself a product with various inputs, and can, like Ao, be described by a function which is characteristic of the structure and

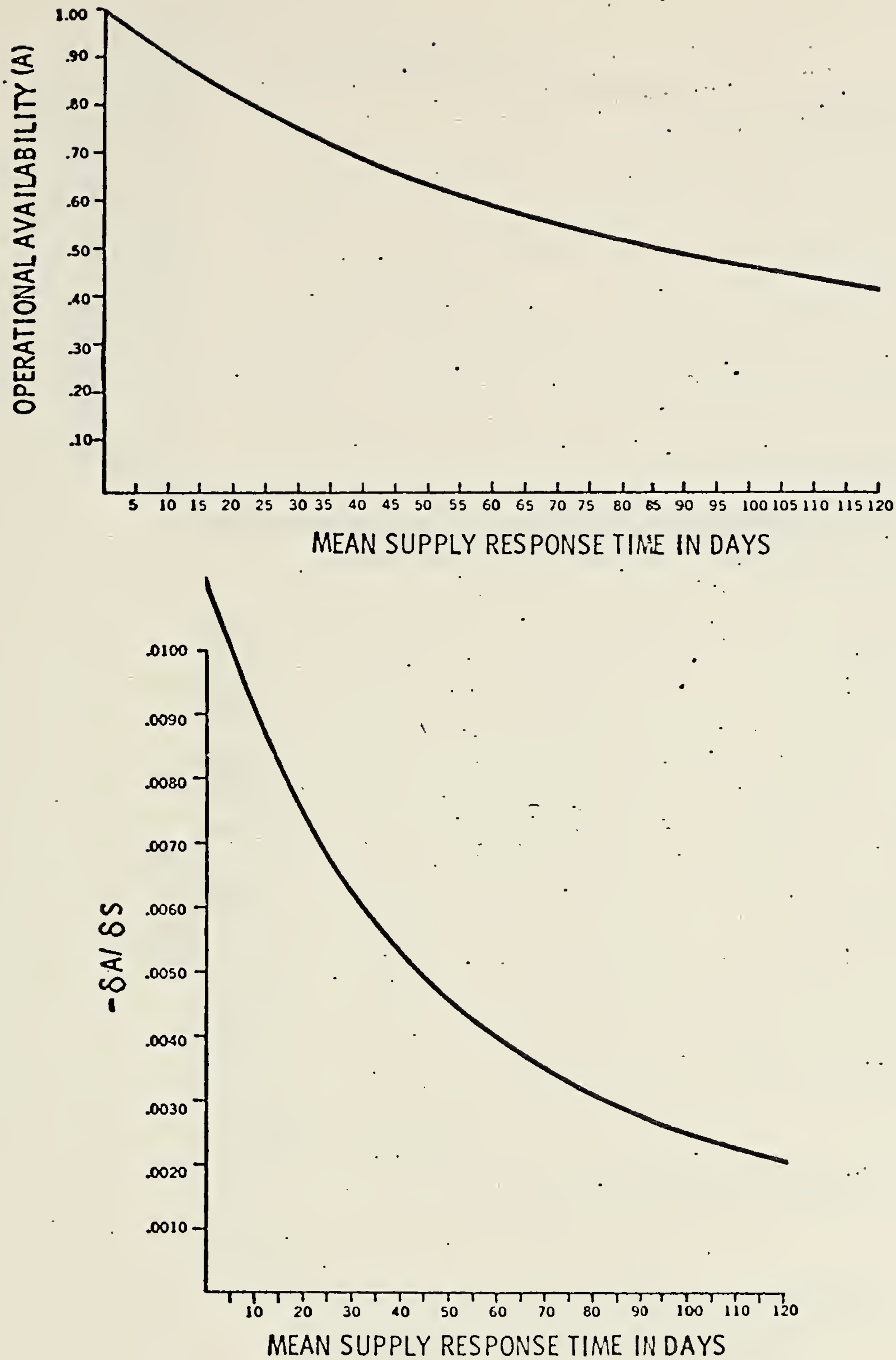

FIGURE 7. Operational Availability of AN/WRT2 Transmitting Set, Radio (MTBF = 2126 Hrs.; MTTR = 10.0 Hrs.)

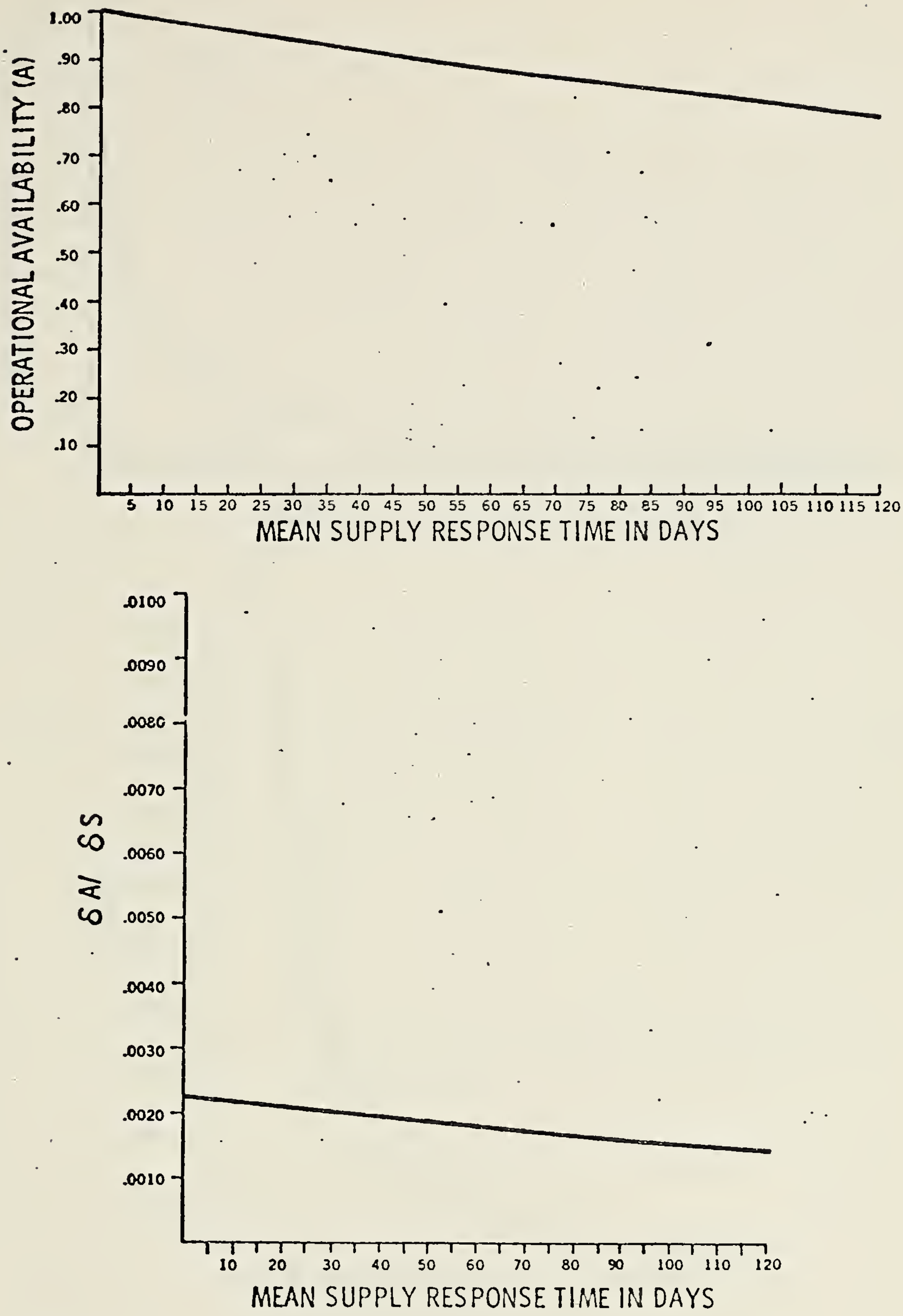

FIGURE 8. Operational Availability of AN/WRC1 Transceiver, Radio (MTBF = 10478 Hrs., MTTR = 6.3 Hrs.)

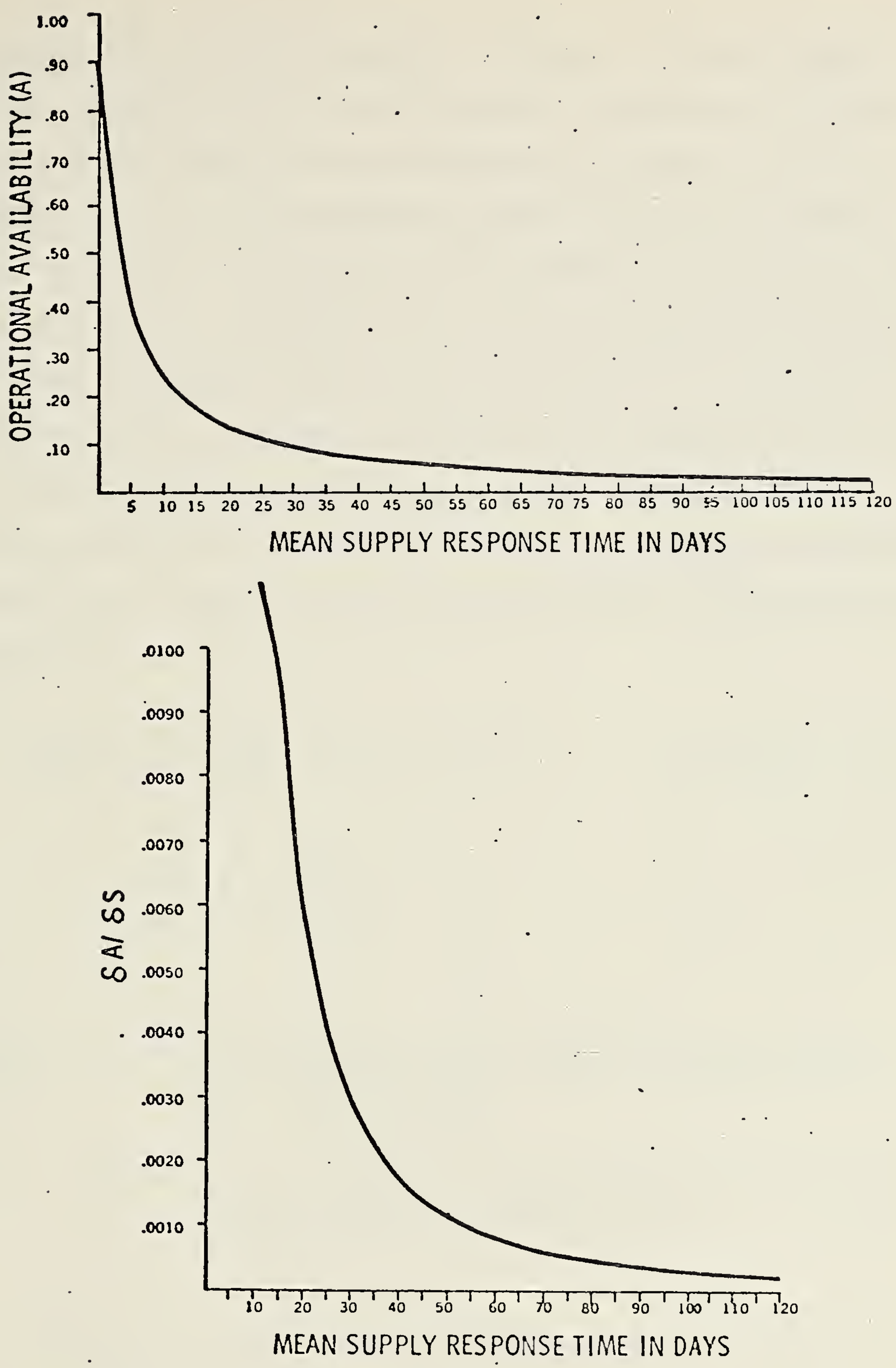

FIGURE 9. Operational Availability of AN/ULQ 6A Repeater, Countermeasures, ECM, Pulse (MTBF = 79 Hrs., MTTR = 9.9 Hrs.)

behavior of the Supply System. Imagine a supply system with n echelons, the first being the storeroom of the ship and the n^{th} being the manufacturer of the part. If the failed part can be supplied from the ship's storeroom, it is; otherwise, a requisition is forwarded to the next echelon, which supplies the item if it can. Otherwise, the requsition is sent through successive echelons until it is supplied or manufactured. The MSRT observed by the mechanic on the ship is just the sum of the response times of each echelon multiplied by the fraction of total requirements the echelons satisfied. Hence, the Supply System MSRT function would take the form:

$$\text{MSRT} = S = a_1T_1 + a_2T_2(1 - a_1) + \ldots + a_nT_n \prod_{i=1}^{n-1} (1 - a_i)$$

$$= \sum_{j=1}^{n} a_jT_j \prod_{i=1}^{j-1} (1 - a_i)$$

where $a_j \equiv$ the probability that the j^{th} echelon will satisfy an end-use requisition not satisfied by a lower echelon;

$T_j \equiv$ the time elapsing from mechanic's stated need for the material until the mechanic receives material from the j^{th} echelon.

To get an idea of what this model says, we can assume a 4-echelon supply system comprised of ship's storeroom, a MLSF ship, an ICP, and finally the manufacturer of the

part. This model of the Supply System would entail eight variables which affect MSRT.

$$S = a_1T_1 + a_2T_2(1-a_1) + a_3T_3(1-a_1)(1-a_2)$$

$$+ a_4T_4(1-a_1)(1-a_2)(1-a_3) \quad \text{(see Figure 10)}$$

We are interested in discovering which of the eight variables we could modify so as to obtain maximum reduction in MSRT. At present, cost data are not readily available, so we will assume equality of costs. In an effort to reduce the large number of combinations of variables which might be investigated, realistic values have been assigned to all but two variables for each examination of the supply MSRT function.

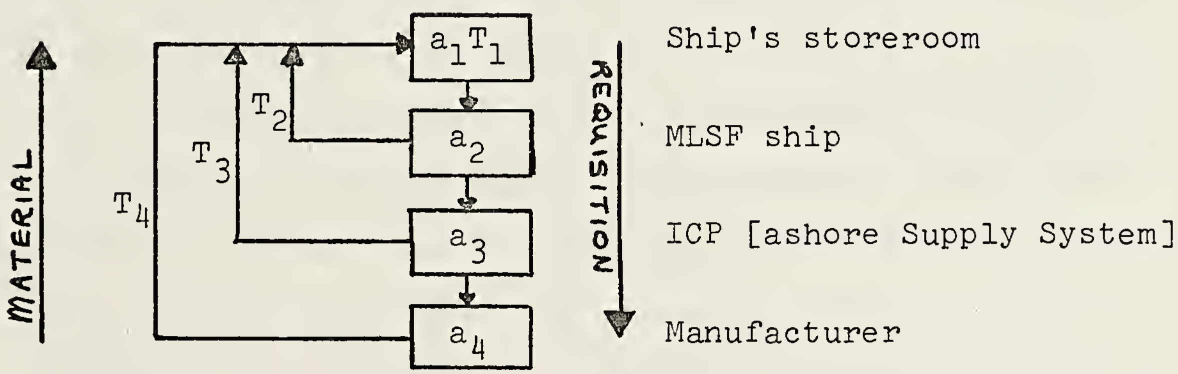

Figure (10)

Four-Echelon Supply System

First, look at the MSRT function for input variables T_2 and T_3 holding the other variables fixed at $a_1 = 0.80$, $a_2 = 0.70$, $a_3 = 0.75$, $a_4 = 1.0$ (material is always ultimately available from the manufacturer), $T_1 = 0$ (if part available on the ship, time to issue part is negligible), and $T_4 = 180$ days (for the manufacturer to supply the part it takes an average of six months). For these values, S = 0.14 $S = 0.14T_2 + 0.45T_3 + 2.7$, or setting S at different values $\overline{S}$, we get

$$T_3 = (22.2\overline{S} - 60) - 3.1T_2$$

As seen in Figure 11, the contours of this MSRT function with T_2 and T_3 as inputs are straight lines with slope -3.1. This says that a unit decrease in T_2 is worth approximately 3.1 units decrease in T_3. Thus we see that S can be reduced from ten to eight days by either reducing T_2 by 14 days or T_3 by 43 days. Observe the dramatic reduction in T_2 or T_3 that is necessary to reduce S to five days.

When the values of a_1 and a_3 are increased, holding T_3 at 60 days and raising supply effectiveness at the third echelon (a_3) from 0.75 to 0.85 allows the average response time T_2 to go from just under 33 days to 39 days while maintaining at 10-day MSRT. However, if we increase a_1 from 0.80 to 0.85 we could let T_2 increase from 33 to 56 days and still maintain the 10-day MSRT.

Figure 12 indicates the effect of changing the input factors, a_2 and a_3. Notice the dramatic increase in a_2

$a_1 = 0.80 \qquad a_4 = 1.0$

$a_2 = 0.70 \qquad T_1 = 0$

$a_3 = 0.75 \qquad T_4 = 180$ days

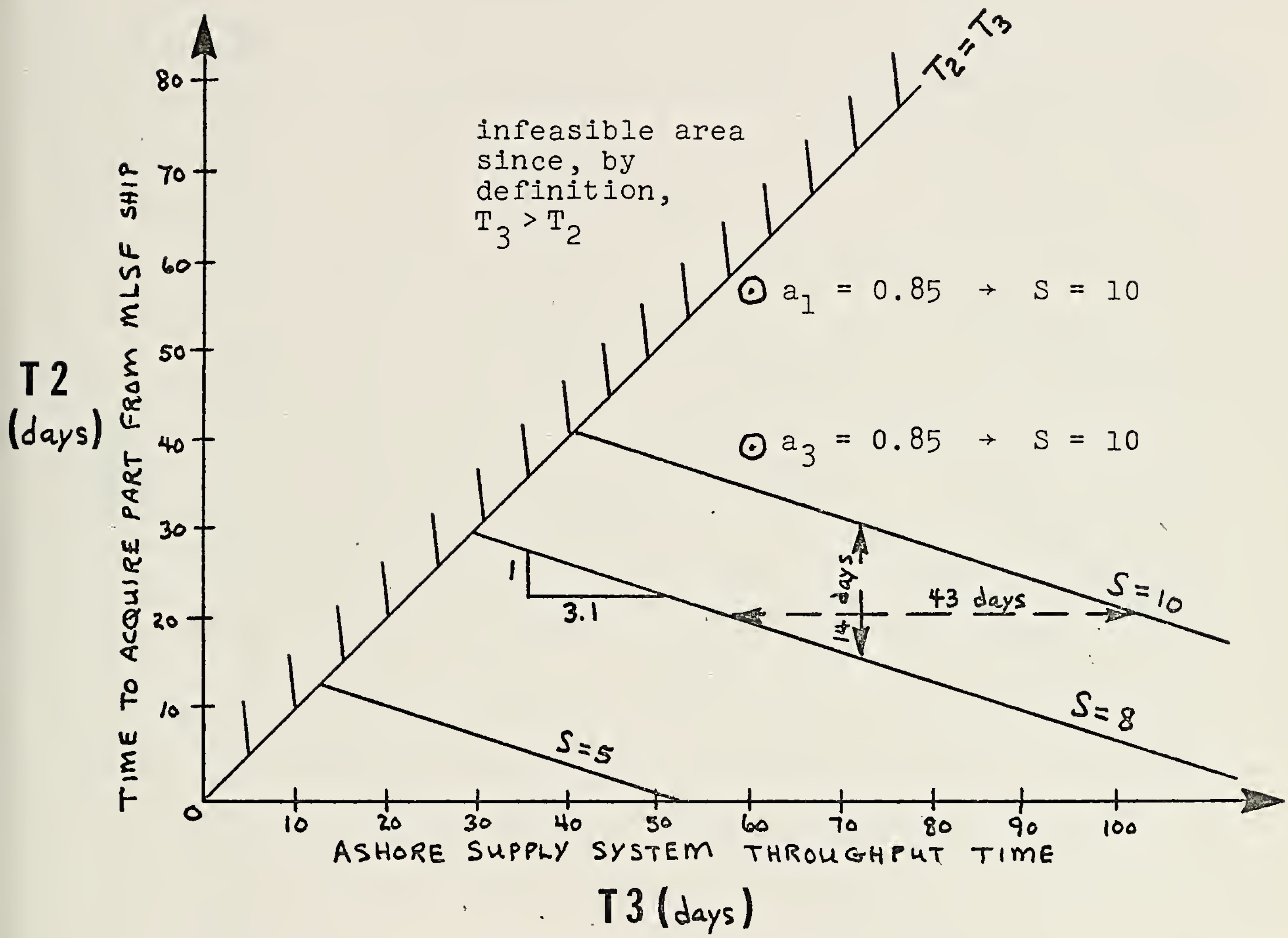

FIGURE 11. Contours of MSRT (S)

$a_1 = 0.8, \quad a_4 = 1.0, \quad T_1 = 0, \quad T_2 = 10, \quad T_3 = 60, \quad T_4 = 180$

$S = 36 - 34a_2 - 24a_3 + 24a_2a_3$

or, in terms of fixed S,

$$a_2 = \overline{S} - 36 + 24a_3/(24a_3 - 34)$$

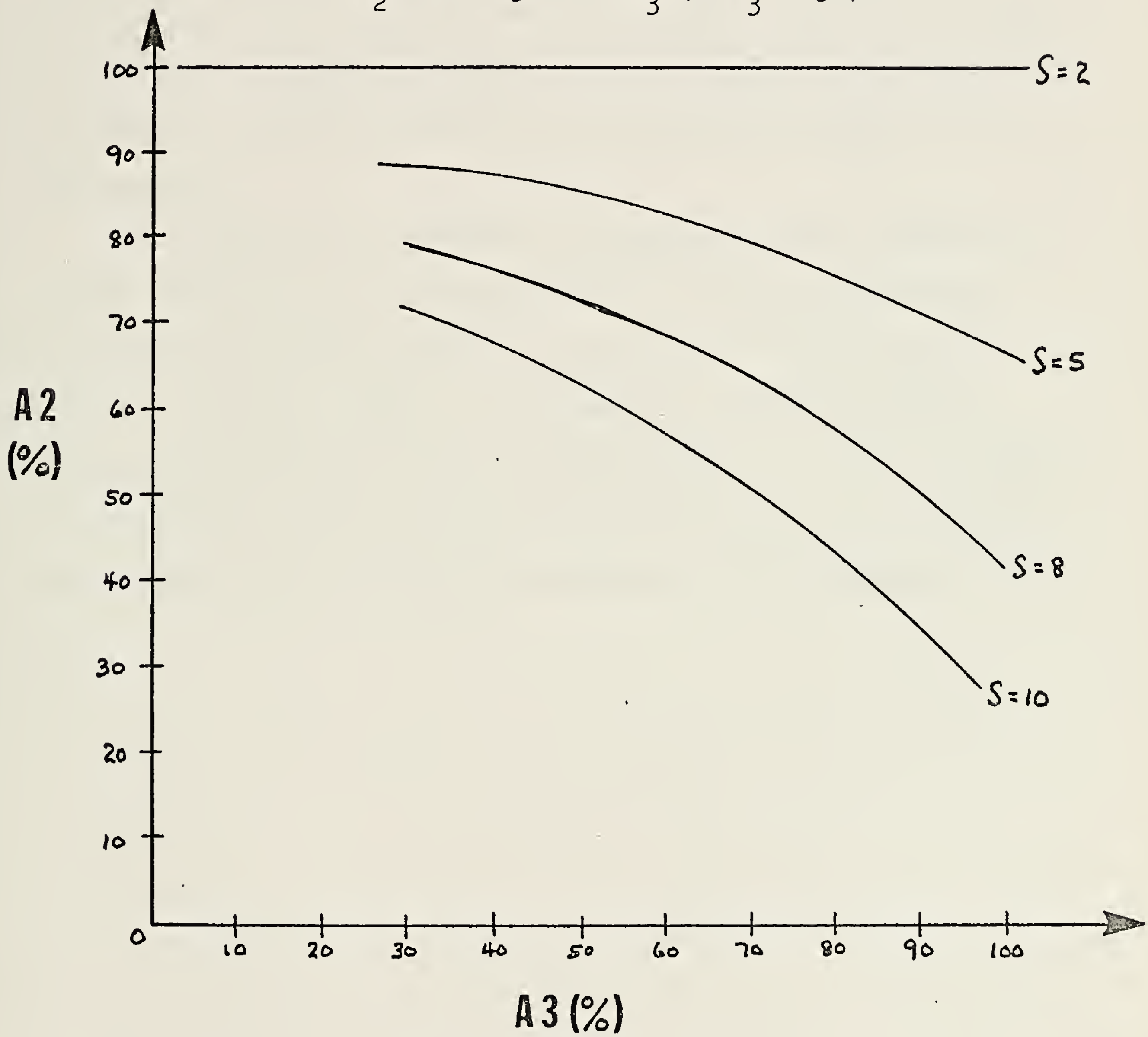

FIGURE 12. Contours of MSRT(S)

that is required to decrease MSRT from ten to five days and to get MSRT down to two days requires an increase of a_2 of 100 percent.

Figure 13 shows the results of treating a_2 and T_2 as the input factors. When a_2 is in the area of 0.70, which is close to real life, one can reduce MSRT from over 17 days to close to 11 days by either reducing T_2 from approximately 110 days to about 30 days or by increasing a_2 from 0.70 to almost 100%.

This chapter has stressed that logistic delay time and supply response time in particular is of major importance in achieving desired levels of operational availability. Tradeoffs between supply and maintenance (MSRT and MTBF) should be considered when allocating resources within NAVMAT, and tradeoffs between stock and manpower (A_i and T_i) should be considered when allocating resources within NAVSUP.

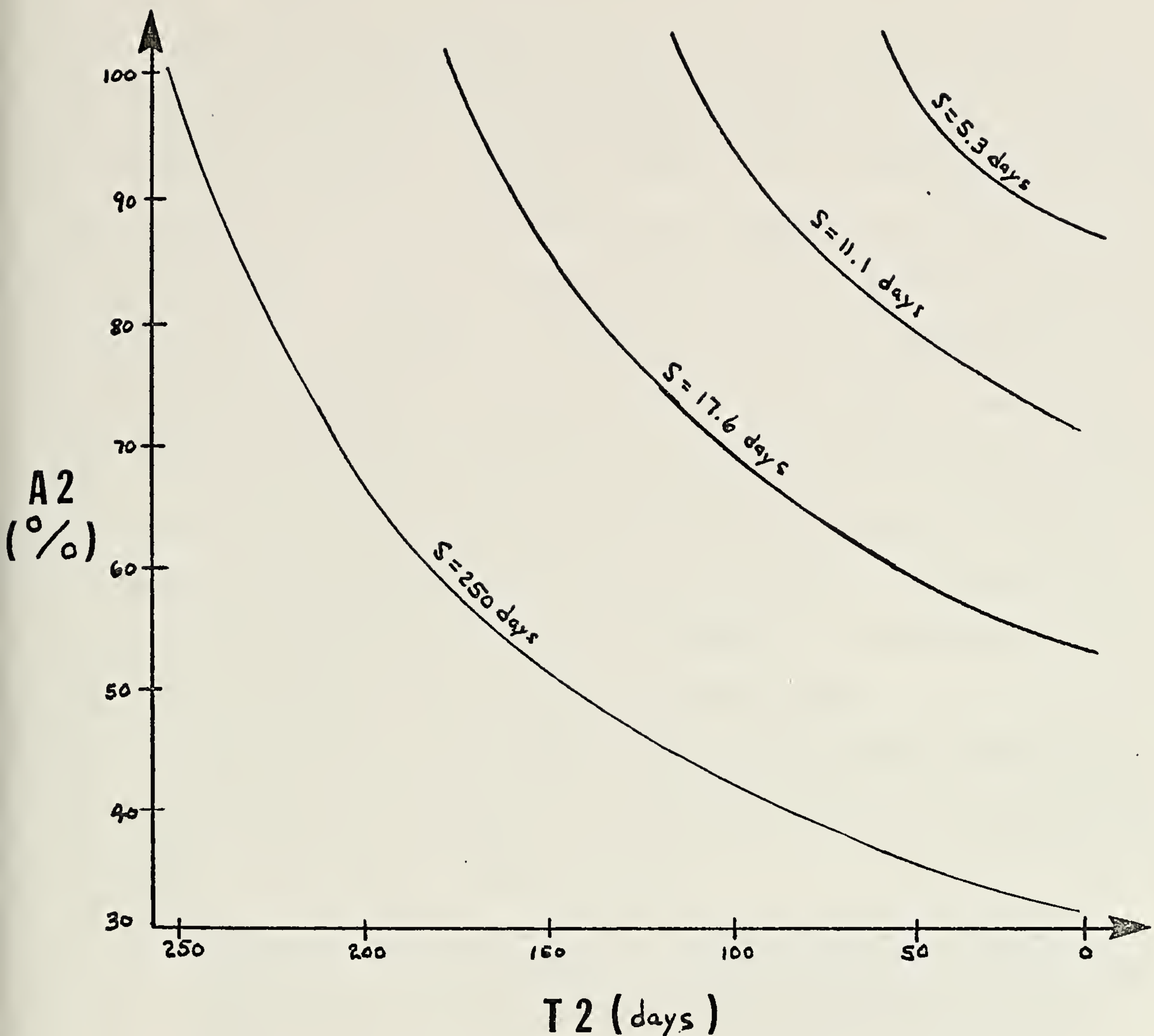

FIGURE 13. Contours of Operational Availability (Ao) and MSRT(S)

V. A PROPOSED NAVSUP OMN BUDGET JUSTIFICATION MODEL

There are many ways to allocate the total funds for support available to the Systems Commands within the Naval Material Command. Analyses which do not consider the alternative allocation of funds within NAVMAT are "suboptimizations" since their impact on other parts of the system has generally not been considered. In February of 1974, NAVSUP requested that FMSO develop a model of the Supply System that takes into account the interaction of supply, maintenance, design, and end-item production in sufficient breadth and detail to permit statements of benefits and tradeoff possibilities. The specific aim was the development of a model which would assist NAVSUP in justifying its OMN budget.

Gates [7] of the Supply System Performance Evaluation Department used marginal analysis to develop a mathematical model of the Navy Supply System.

> Briefly, the approach was to describe the system in terms of production and cost fucntions, collapse these functions into their marginal values, equate the ratios of marginal physical products and marginal costs and then solve for the variable of interest... There are two implied assumptions in the model and one explicit assumption. The implied assumptions are: (a) the system is operating in an economically efficient manner, and (b) input prices are determined in a purely competitive market. The explicit assumption is that Mean Supply Response Time is a function of only manpower and stock that are available in the supply system and that this relationship follows an exponential function. [Gates,7]

Marginal improvements in Supply System Response Time for a particular weapon system are assumed to be proportional, by a factor of α and β, to respective increases in manpower and months of stock for that weapon system.

The assumption about response time, stated mathematically is

$$R = \gamma \exp\{-\alpha M - \beta S\}$$

where: R = Mean Supply Response Time (MSRT)

M = Supply System Man Months

S = Months of Stock

α,β,γ = Regression Coefficients.

This formulation of MSRT differs from that discussed in Chapter IV of this paper. The earlier discussion of MSRT treated it from a structural viewpoint, i.e., response time is actually the sum of throughput times at various echelons weighted by the probability that the requisition will reach each echelon. The formulation above treats MSRT as being correlated with the manpower and stock levels of the entire supply system. A method to be used to determine this correlation in such an exponential relationship was proposed by Gates [8]. The above function has the following properties: (a) response time monotonically decreases as manpower and stock levels increase; (b) response time approaches zero

as manpower and stock levels increase without bound and (c) when M and S are zero then R = γ, i.e., there is a value for response time even if there is no supply system.

The OMN budget justification model developed by FMSO is

$$M = \frac{\ln[(c_1 + c_2 \exp\{-IL\})N\alpha\beta\gamma] - \ln[k_1(\beta c_3 + \alpha c_4)] - \beta S}{\alpha},$$

where

M = Supply System Man-months

F = Force Level Unit (FLU) (e.g., aircraft, ship, etc.)

c_1 = Cost of a FLU

c_2 = Cost of operating a FLU per month

c_3 = Cost of a Man-month (\$13.84/hr x 172 hrs = \$2,380)

c_4 = Value of Monthly Stock Issues

I = Nominal Interest Rate

Ao = Probability a FLU is operational

L = Life Expectancy of a FLU (months)

k_1 = MTBF, Mean Time Between Failures (months)

S = Number of Months of Stock in Supply System (On hand dollar value divided by c_4)

N = Number of Operational FLUs = (F)(Ao)

α,β,γ = Regression Coefficients for Supply System Response Time.

Appendix B gives the complete mathematical development of the above model as taken from Ref. 7.

For the model to be dimensionally correct, each additive term must have the same dimensions as M, i.e., man-months.

The simplest additive term (β)S, should for example represent man-months. From the definition of the variables as given in Ref. 7, the dimensions assigned to each variable are not obvious. It appears that M represents optimal man-months for a weapon system comprised of many FLUs, but k_1 seems to represent MTBF of an FLU. Once the level of aggregation is determined, weapon system or FLU, there exists a measurement problem in acquiring the data as with any model.

The model gives the optimal level of supply system man-months to support a particular weapon system, given a set of input values for that weapon system. Total man-months for supply support of the Navy would then have to be estimated from the sum of optimal values for each individual weapon system. The total would be adjusted downward to account for overlapping areas among weapon systems; the total would be adjusted upward to account for supply system workload such as logistic support programs not directly related to U. S. Navy weapon systems. It is not clear whether this procedure would result in total manpower requirements above or below the sum of optimal levels for each weapon system. Total NAVSUP manpower requirements in dollars for the OMN budget could then be obtained by multiplying the total man-months required by the cost of a man-month.

To make a preliminary test of their model, FMSO needed base values for the input variables. They obtained several of the input values from figures used by the Center for

Naval Analyses (CNA) [2]. Those figures were elements in the costs used in estimating the production function parameters for a hypothetical aircraft; specific costs, which are classified, are given in an unpublished manuscript referred to in Ref. 2. Other values (c_3, S, α, β, γ) were specified by FMSO as being reasonable estimates.

The following is a list of base input values taken from Ref. 7:

c_1 = \$2,200,000	Aircraft Cost
c_2 = \$23,100	Aircraft Operating Cost
c_3 = \$2,380	Cost of a Man-month (\$13.84/hr x 172 hrs.)
c_4 = \$110,000	Value of Monthly Issues
I = 0.10	Nominal Interest Rate
L = 100 months	Service Life
k_1 = 0.1344 months	MTBF (100 hrs ÷ 720 hrs./mo.)
S = 12 months	Stock Level
N = 8	Number of Operating Aircraft
γ = 9.0	
α = 0.01	Representative Regression Coefficients
β = 0.05	

The results of running the model and incrementing N, S, K, α, β by plus and minus 25% of the base values are included in Table X.

	Number of Aircraft (N)	Stock Level (S)	MTBF (k_1)	α	β
- 25%	529.0	573.1	587.0	740.0	547.1
+ 25%	579.8	542.0	535.7	447.9	563.0

Base value = 558.0 man-months

TABLE X.

Optimal Level of Supply System Man-Months (M) for Hypothetical Aircraft for Various Levels of Input Values.
[Source: Reference 7, Table, p. 2.
Each figure divied by c_3 = $2,380.]

FMSO interpreted the values in the table as showing that the supply system manpower requirement for this weapon system increases as the number of operating aircraft comprising the weapon system increases; it decreases as the number of months of stock increases or as the time between failures increases. It is sensitive to regression coefficient α but not β. FMSO recommended to NAVSUP that a project be approved to develop actual weapon system parameters to use in validating the model.

Gates [8] suggests a logarithmic transformation of the expression for R to obtain

$$\ln R = \ln \gamma - \alpha M - \beta S.$$

The regression coefficients α, β, and γ could then be estimated using a multiple regression procedure. For input data a time series of response time, man-months expended, and months of stock available would be used.

VI. CONCLUSION

NAVSUP cannot obtain OMN funds on the basis of need alone; national defense resources are becoming more severely constrained each year. This factor, along with the pressures to conform to PPBS practices, have started a trend within NAVSUP to justify budget requests as being least-cost allocations to achieve a given level of output.

NAVSUP faces a political dilemma when specifying its objective. It is forced to "advertise" two conflicting objectives. The fleet is told that the goal is minimizing MSRT; the budgeteers and Congress are told that the goal is achieving a set level of MSRT at least cost. In either case, NAVSUP has chosen MSRT as the most relevant measure of its output effectiveness. It has assigned a group of professionals within FMSO (SSPED) the difficult task of developing techniques of measuring MSRT and estimating the input costs associated with achieving lower levels of MSRT for a given weapon system. As a continuation of this effort, supply operation activities' effectiveness should be measured as to their impact on system output (MSRT), rather than on their net or POE effectiveness or other parochial measures of effectiveness alone.

The current NAVSUP budget justification procedure, which is based on workload measurement, is not adequate since it provides no means of evaluating tradeoffs between NAVSUP

output and hardware system commands' output. The lack of an analytical model encompassing both supply and maintenance prevents statements about "optimal" allocations. In addition, the current procedure is self-serving since workload is based on allowance lists which are developed to a large extent by NAVSUP activities. Presently, management programs are funded by adjusting priced-out workload upward; they should be funded by proposed savings in the workload area. Improvement programs should increase productivity which should be reflected in the workload model.

The Gates model is a good start towards the application of economic analysis to resource allocation decisions effecting support costs (OMN) within NAVMAT. There do seem to be problems with dimensionality within the model between individual force level units and weapon system level measurements. The procedure for aggregating manpower requirements by weapon system to total supply system manpower requirements must be carefully considered. Some consideration must be made for including non-weapon system manpower requirements such as the support of other support organizations like medical. Finally, the usefulness of the model is contingent upon the development of weapon system parameters and further validation with actual data.

VII. SUGGESTED AREAS OF RESEARCH

During the investigative stages of this thesis, the following ideas for possible research were proposed by Mr. J.A. Gates of the Fleet Material Support Office (FMSO). A processing model would assist in the use of MSRT as a management tool; the combination of data to increase sample sizes would allow the use of more analytic techniques; and demand forecasting and stocking criteria improvements are applicable to the analysis of resource allocations as well as to other problems.

A. PROCESSING MODEL

There are four time segments that are being investigated in response time problems. They are:

Requisition Submission Time
Availability Determination Time
Storage Site Processing Time
Transportation Time

Information on arrival rates of requisitions and the service times for each segment are available. The development of a simple queuing model using Erlang distributions for service times (or other distributions) would assist FMSO in evaluating proposed stock point or ICP management changes.

B. DATA COMBINATION

A frequent difficulty encountered in the analysis of data is the lack of a sufficiently large number of observations,

e.g., FMSO only has eight quarters of stock item demand history, 15 months of requisition processing time information, etc. The development of a practical approach of pooling time series and cross-sectional (inter-activity) would allow FMSO to increase the sample size in most of their quantitative analyses to obtain more significant results. An approach similar to that in Woodbury's thesis [23] might prove to be useful.

C. DEMAND FORECASTING

Definite seasonal patterns in aggregate demand exist, e.g., NAVSUP sales in June are always the highest each year whereas sales in July are almost always the lowest; December sales are down, but January sales are up. Current NAVSUP demand forecasting techniques cannot handle this kind of autoregressive process. The development of other methods of forecasting demand and sales is required.

The development of valid program relationships between demands for parts and fleet operations should be pursued. An extension of the Lippert and Lee thesis [13] to further identify the proper variates affecting demands could lead to better demand forecasting techniques.

D. STOCKING CRITERIA

NAVSUP is participating on a DOD committee which is working on the development of stocking criteria for provisioning. NAVSUP does not now have a usable retail stocking

criterion for stock points. A primitive heuristic criterion (stock if four demands occur in 6 months) is currently in use. Thesis work in this area could offer worthwhile improvements.

APPENDIX A

THE CORRELATION BETWEEN FORCE LVELS AND NAVSUP WORKLOAD

To show that a significant correlation exists between the three force level indicators and the three workload indicators, an abstract composite index for each set was obtained by using manpower utilized as a common denominator. The following procedure is as described in Reference 7.

COMPOSITE FORCE LEVEL INDEX

formula:

$$X = \sum_i \left[\frac{F_{in}}{F_{i0}} \cdot \frac{M_{in}}{\sum_i M_{in}} \right]$$

Key

F = Force Level
M = Man-month
n = Given year
O = Base year
i = Force Level Indicator

From the illustrative data below X is computed to be X = 1.079.

Force Level Indicators	(0) FY 1	(n) FY 2	
(1) Ships: # of support items (000)	6,000	6,800	$\frac{F_{1n}}{F_{10}} = \frac{6800}{6000} = 1.133$
(2) Aircraft: # of support items (000)	30,000	32,000	$\frac{F_{2n}}{F_{20}} = \frac{32,000}{30,000} = 1.067$
(3) Personnel:	500,000	450,000	$\frac{F_{3n}}{F_{30}} = \frac{450,000}{500,000} = 0.900$

Man-Month Weights for Force Levels Index

		$M_{in} / \sum_i M_{in}$
(1) Ships:	$M_{1n} = 4{,}538$	0.597
(2) Aircraft:	$M_{2n} = 1{,}808$	0.238
(3) Personnel:	$M_{3n} = 1{,}254$	0.165
TOTAL	$7{,}600 = \sum_i M_{in}$	

The man-month weights are derived by assigning (using cognizance symbols) the manpower utilized by supply activities to either ships, aircraft, or personnel. For instance, hours expended on cognizance 2R items (Aeronautical Material) was assigned to "Aircraft Support Items Force Level." To provide the weighting factors for the workload indicators, the manpower utilization is further identified to either Line Items Received and Issued, Measurement Tons Received and Issued, or Measurement Tons In Store. Illustrative data is shown below.

Man-Months Associated With Force Level and Workload Indicators

	Line Items Received and Issued	Measurement Tons Received and Issued	Measurement Tons In Store	FORCE LEVEL TOTALS
Ships	1538	1000	1000	4538
Aircraft	308	500	1000	1808
Personnel	154	600	500	1254
WORKLOAD TOTALS:	2000	2100	3500	7600

Composite Workload Index

formula:

$$Y = \sum_i \left[\frac{W_{in}}{W_{i0}} \cdot \frac{M_{in}}{\sum_i M_{in}} \right]$$

Key

W = Workload
M = Man-month
n = given year
0 = base year
i = Workload Indicator

From the illustrative data below, Y is computed to be

Y = 1.072.

Workload Indicators	(0) FY 1	(n) FY 2	
(1) L/I Rec & ISS (000)	15,000	15,500	$\frac{W_{1n}}{W_{10}} = \frac{15,500}{15,000} = 1.033$
(2) M/T Rec & ISS (000)	10,000	10,200	$\frac{W_{2n}}{W_{20}} = \frac{10,200}{10,000} = 1.020$
(3) M/T In Store (000)	4,000	4,500	$\frac{W_{3n}}{W_{30}} = \frac{4,500}{4,000} = 1.125$

Man Month Weights for Workload Index

		$M_{in}/\sum_i M_{in}$
(1) L/I Rec & Iss:	M_{1n} = 2000	0.263
(2) M/T Rec & Iss:	M_{2n} = 2100	0.276
(3) M/T In Store:	M_{3n} = 3500	0.461
TOTAL	7600 $= \sum_i M_{in}$	

Having the two variables, the independent, or force level composite index (X) and the dependent, or workload composite index (Y) for fiscal years 1955 through 1961, the data were related using a simple linear regression model. The resultant coefficient of correlation (R) was 0.8717 and the coefficient of determination (R^2) indicated that approximately 75% of the variance in the workload composite index for supply operations of NAVSUP is attributable to variation in the force level composite index based on the forces this workload supports. The linear equation $Y = 0.237 + 0.744\ X$ was obtained from the regression of the data.

APPENDIX B

MATHEMATICAL DEVELOPMENT OF BUDGET JUSTIFICATION MODEL
Gates [15]

1. Definition of variables and constants.

F - Force Level Units (FLU) (e.g. aircraft, ships, etc.)

R - Mean Supply Response Time (MSRT)

M - Supply system man-months

S - Months of stock

k_1 - Mean Time Between Failures (MTBF)

k_2 - Mean Time to Repair (MTTR)

c_1 - Cost of a FLU

c_2 - Cost of operating a FLU per month

c_3 - Cost of a man-month

c_4 - Cost of a month of stock

α, β, γ - Regression coefficients

ΔP - Marginal physical product

ΔC - Marginal cost

I - Nominal interest rate

L - Life expectancy of a FLU (months)

A_o - Operational availability

N - Operational Force Level Units

2. Compute marginal physical products.

Define:

N = total number of operating Force Level Units

= number of Force Level Units x probability a FLU is operational

$$N = FA_o = F\left(\frac{k_1}{k_1 + k_2 + R}\right) = \frac{k_1 F}{k_1 + k_2 + R}$$

First partial derivatives.

(1)

$$\Delta P_F = \frac{\partial N}{\partial F} = \frac{k_1}{k_1 + k_2 + R}$$

(2)

$$\Delta P_R = \frac{\partial N}{\partial R} = \frac{-k_1 F}{(k_1 + k_2 + R)^2}$$

3. Compute marginal costs.

C_F = (flyaway cost + operating cost) x FLU

$$C_F = (c_1 + c_2 e^{-IL})F$$

First partial derivative.

(3)

$$\Delta C_F = \frac{\partial C_F}{\partial F} = c_1 + c_2 e^{-IL}$$

C_R = (cost of a man-month x man-months) +

(cost of a month of stock x months of stock)

$= c_3 M + c_4 S$

Using total partial derivative.

$$\Delta C_R = \frac{\partial C_R}{\partial R} = \frac{\partial C_R}{\partial M}\frac{\partial M}{\partial R} + \frac{\partial C_R}{\partial S}\frac{\partial S}{\partial R}$$

(4)
$$= c_3 \frac{\partial M}{R} + c_4 \frac{\partial S}{R}$$

(5) Assume $R = \gamma e^{-\alpha M - \beta S}$

then $M = \dfrac{\ln \gamma - \ln R - \beta S}{\alpha}$

and $S = \dfrac{\ln \gamma - \ln R - \alpha M}{\beta}$

Taking the partial derivatives.

$$\frac{\partial M}{\partial R} = - \frac{1}{\alpha R}$$

$$\frac{\partial S}{\partial R} = - \frac{1}{\beta R}$$

Substituting into equation (4).

(6) $$\frac{\partial C_R}{\partial R} = - \frac{c_3}{\alpha R} - \frac{c_4}{\beta R} = - \frac{1}{R} \left(\frac{c_3}{\alpha} + \frac{c_4}{\beta}\right)$$

Substituting equation (5) for R.

$$\frac{\partial C_R}{\partial R} = - \frac{1}{\gamma e^{-\alpha M - \beta S}} \left(\frac{c_3}{\alpha} + \frac{c_4}{\beta}\right)$$

(7)

$$= - \frac{c_3\beta + c_4\alpha}{\alpha\beta\gamma e^{-\alpha M - \beta S}}$$

4. Using Concept of Marginal Ratios

(8)

$$\frac{\Delta P_F}{\Delta P_R} = \frac{\Delta C_F}{\Delta C_R}$$

Substituting equations (1), (2), (3), (7) into equation (8).

$$\frac{\dfrac{k_1}{k_1 + k_2 + R}}{-\dfrac{k_1 F}{(k_1 + k_2 + R)^2}} = \frac{c_1 + c_2 e^{-IL}}{-\dfrac{c_3\beta + c_4\alpha}{\alpha\beta\gamma e^{-\alpha M - \beta S}}}$$

(9)

$$\frac{k_1 + k_2 + R}{F} = \frac{(c_1 + c_2 e^{-KL})(\alpha\beta\gamma e^{-\alpha M - \beta S})}{c_3\beta + c_4\alpha}$$

Since

$$N = \frac{k_1 F}{k_1 + k_2 + R}$$

(10)

$$R = \frac{k_1 F}{N} - k_1 - k_2$$

Substituting equation (10) into equation (9)

$$\frac{k_1 + k_2 + \frac{k_1 F}{N} - k_1 - k_2}{F} = \text{Right Hand Side}$$

$$\frac{k_1}{N} = \frac{(c_1 + c_2 e^{-IL})(\alpha\beta\gamma e^{-\alpha M - \beta S})}{\beta c_3 + \alpha c_4}$$

Solving for M.

$$e^{-\alpha M - \beta S} = \frac{k_1(\beta c_3 + \alpha c_4)}{(c_1 + c_2 e^{-IL})N\alpha\beta\gamma}$$

$$M = \frac{\ln[\cdot] + \beta S}{-\alpha}$$

or

$$M = \frac{\ln[(c_1 + c_2 e^{-IL})N\alpha\beta\gamma] - \ln[k_1(\beta c_3 + \alpha c_4)] - \beta S}{\alpha}$$

To compute the dollar value requirement

$$\$M = c_3 M$$

To compute the total aircraft needed

$$F = N/A_o$$

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